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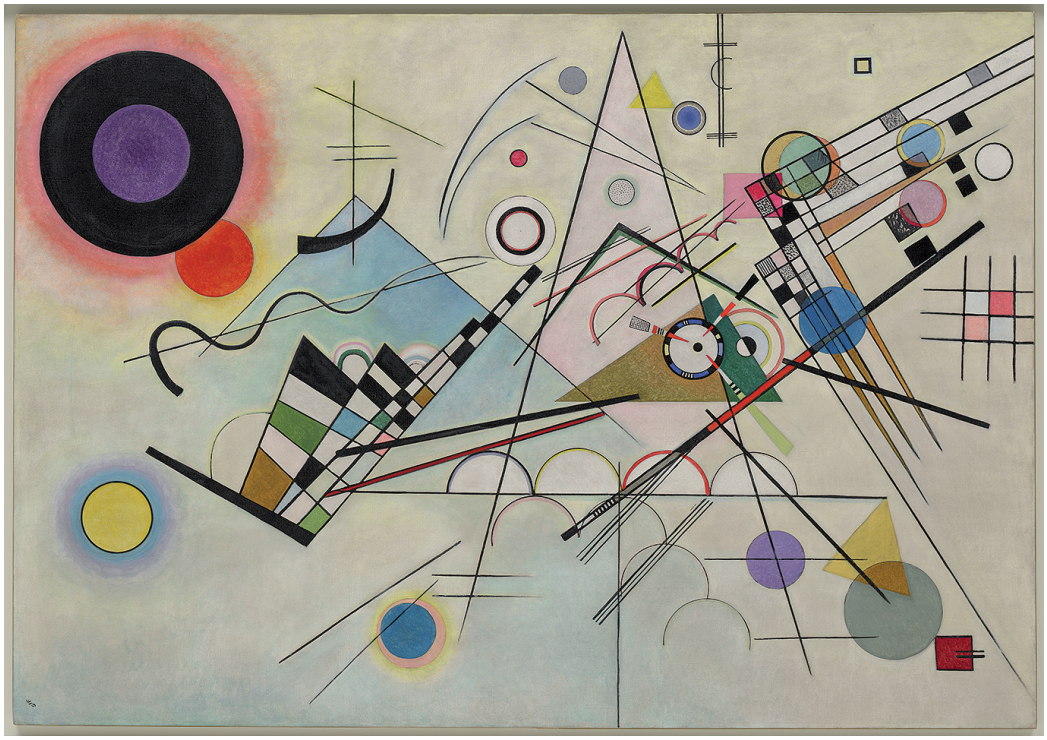
313

Imre Lahdelma

At the Interface Between Sensation and Emotion

Perceived Qualities of Single Chords



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Editors
Tuomas Eerola
Department of Music, Art and Culture Studies, University of Jyväskylä
Pekka Olsbo, Ville Korkiakangas
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"...I am very grateful to you for challenging me to this discussion because, as an afterthought to it, the question emerged before me: what is the relation between…a chord as a physical phenomenon and the emotion signified by it? For the time being I cannot answer this question...Could you?"

-- Béla Bartók in a letter to Stefi Geyer (dated 27 July 1907), as cited in Frigyesi (1998, p. 147)

ABSTRACT

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The focus of this dissertation is to investigate the perception of single chords, both in terms of perceived emotions and psychoacoustic qualities. Previous empirical research on harmony perception has mainly been concerned with horizontal aspects of harmony: studies focusing on vertical harmony perception have been rare. The current work aims to fill some of the still evident gaps between musicology, music psychology, and psychoacoustics with regard to single chord perception by combining both empirical and theoretical approaches.

The work comprises three publications, based on two large-scale empirical experiments conducted with the aim of drawing the attention of both expert and inexpert listeners to have a substantial, heterogeneous, and international participant pool. The applied chord stimuli spanned common triads and tetrads with inversions, and also more rare chord sonorities in the form of pentads and hexachords. Altogether two distinct timbres were used, piano and strings. The stimuli were analyzed in terms of psychoacoustic properties, including e.g., roughness, harmonicity, and sharpness to further account for the obtained results.

The results suggest significant differences in emotion perception across different chord types. The inversions and register contributed to the evaluations significantly, non-musicians distinguishing between triadic inversions similarly to musicians. Mildly dissonant chords were more preferred than consonant chords, regardless of musical sophistication or music preferences. Certain chords, especially the major seventh chord played on the strings, conveyed the emotion of nostalgia/longing effectively. New theoretical models are suggested based on the results and psychoacoustic data to explain the capacity of certain chords to convey complex emotions, and the perception of consonance/dissonance in single chords.

Keywords: Chord, emotion, vertical harmony, harmony perception, consonance/dissonance, psychoacoustics

Author's address

Imre Lahdelma
Department of Music, Art and Culture Studies
P.O. Box 35
FI 40014 University of Jyväskylä, Finland
imre.lahdelma@jyu.fi

Supervisors

Professor Tuomas Eerola
Department of Music
Durham University, UK

Lecturer Riitta Rautio
Department of Music, Art and Culture Studies
University of Jyväskylä

Reviewers

Professor Justin London
Department of Music
Carleton College, USA

Senior Lecturer Marcus T. Pearce
School of Electronic Engineering and Computer Science
Queen Mary College, University of London, UK

Professor Nicola Dibben
Department of Music
University of Sheffield, UK

Opponent

Professor Elvira Brattico
Department of Clinical Medicine
Center for Music in the Brain
Aarhus University, Denmark

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Finally, I would like to thank my family who has always given me love and support - this work is dedicated to you, and to the memory of my late uncle Aimo Lahdelma (1959-2017).

Jyväskylä, 25 April, 2017
Imre Lahdelma

LIST OF PUBLICATIONS

List of the publications included in this dissertation:

I Lahdelma I., & Eerola, T. (2016). Single chords convey distinct emotional qualities to both naïve and expert listeners. *Psychology of Music, 44*, 37–54.

II Lahdelma I., & Eerola, T. (2015). Theoretical proposals on how vertical harmony may convey nostalgia and longing in music. *Empirical Musicology Review, 10*, 245–263.

III Lahdelma, I., & Eerola, T. (2016). Mild dissonance preferred over consonance in single chord perception. *i-Perception, 7(3)*.

SUMMARY OF PUBLICATIONS

I The first publication aimed to investigate whether single isolated chords convey distinct emotional qualities consistently to both expert and inexpert listeners in an empirical setting. Moreover, the study's interest was to broaden the research question to encompass not only basic emotions such as happiness/joy and melancholy/sadness, but also complex, mixed emotions such as nostalgia/longing. The results suggest that single chords indeed do convey distinct emotions to listeners, and these are perceived consistently regardless of musical sophistication. According to the data, mild dissonance is more preferred than consonance in single chord perception. Timbre and triadic inversions also contributed to the chord evaluations significantly. Psychoacoustic measurements (roughness, brightness, irregularity, spectral flux, and log attack time) were applied to the stimuli to further account for the obtained results.

The author was responsible for co-designing the study, the data collection, contributed to the data analysis, and played the main role in writing.

II The second publication's aim was to suggest theoretical explanations for the capacity of certain chord types to consistently convey the complex, mixed emotion of nostalgia/longing. The three proposed candidate explanations are (1) *learning*, (2) *intrinsic emotional connotations arising from tonal relations*, and (3) *clashing conventions arising from concurrent yet separate affective associations, stemming from certain triad and interval combinations*. These explanations take into account psychological principles, learning, intrinsic principles and conventions within the tonal framework, and their conflicting matches. Psychoacoustic measurements in the form of roughness and harmonicity were harnessed to disentangle and further explain the capacity of certain chord types to convey the emotion of nostalgia/longing.

The author was responsible for writing the article and interpreting the obtained psychoacoustic data.

III The third publication aimed to further disentangle and to replicate the first publication's findings with a second empirical experiment. The main points of interest were the preference of mild dissonance over consonance, and the perceived differences in triadic inversions. The question of register and the randomizing of chord roots was also addressed in the experiment, as these were omitted in the first study to make it more compact. The results suggest that mild dissonance is indeed more preferred than consonance, and this result was largely unaffected by musical sophistication or music preferences. Both musicians and non-musicians distinguished between triadic inversions similarly. Psychoacoustic

measurements in the form of roughness, harmonicity, and sharpness were harnessed to further disentangle the obtained results.

The author was responsible for co-designing the study, the design of the stimuli, the data collection, contributed to the data analysis, and played the main role in writing.

CONTENTS

1 INTRODUCTION

Music is a powerful tool in conveying a wide range of emotions to listeners. As Huron and Margulis (2010) put it: "whether people seek joyful animation or sad nostalgia, music is often the art of choice" (p. 575). Many studies have addressed the role of musical structures conveying emotions to listeners (e.g., Gabrielsson & Lindström, 2010; Gagnon & Peretz, 2003; Juslin & Sloboda, 2010a), but the role of vertical harmony has been somewhat neglected in such studies. As Huron (1994) notes: "little is known about the perception of three or more concurrent pitches" (p. 304). Kuusi (2009) suggests that researchers have rarely studied the emotions or expressions listeners associate with chords, Gabrielsson and Lindström (2010) concurring: "…there is practically nothing on how different kinds of chords…may affect expression" (p. 393). From a theoretical point of view, composers ranging from Jean-Philippe Rameau to Béla Bartók have attended to vertical harmony's emotional connotations, the former acknowledging the power of chords to "excite different passions in us" (Rameau, 1722/1971, p. 154), the latter pondering on the relationship between the chord "as a physical phenomenon and the emotion signified by it" (as cited in Frigyesi, 1998, p. 147). Music therapist and composer Paul Nordoff also suggests that every chord "has its emotional impact, each one carries its emotional quality…" (as cited in Robbins & Robbins, 1998, p. 199).

With regard to emotional qualities conveyed by specifically harmony's vertical dimension in the form of chords, the emphasis has mainly been theoretical (e.g., Cooke, 1959; Meyer, 1956). Moreover, such theorizing has remained anecdotal in nature, lacking scientifically rigorous empirical data. While there have been some empirical attempts to investigate the emotional qualities conveyed by vertical harmony, such studies have either focused exclusively on harmonic intervals (e.g., Costa et al., 2000; Krantz et al., 2004; Maher, 1980; Oelmann & Laeng, 2009), or on the major/minor triad distinction (e.g., Crowder, 1985; Heinlein, 1928; Kastner & Crowder, 1990). The perception of consonance/dissonance in (mostly) triad chords has also been studied empirically by, for example, Bidelman and Krishnan (2011), Cook (1999), Pallesen et al. (2005), and Roberts (1986). Kuusi (2009, 2010, 2011) also touches

upon the question of how listeners perceive single isolated chords aesthetically, but focuses mainly on non-traditional (non-tonal) chords and adjectives defining chord qualities rather than on actual emotions conveyed by chords.

Considering the crucial role vertical harmony plays in Western music (see e.g., Goldman, 1965), this lack of a systematic, empirical research approach particularly on its emotional connotations, seems somewhat surprising. The relative scarcity of studies focusing specifically on vertical harmony and emotions is probably due to the fact that both *harmony* and *emotions* are challenging phenomena to investigate by themselves, let alone when observed together. Discussing the overall lack of psychological studies on music perception before the 1990's, Sloboda (1991) notes that one reason for this scarcity of well-founded psychological research on the emotional aspects of music lies in the difficulty of measuring emotional responses. Another underlying reason proposed by Sloboda to explain the late-blooming of the field of music and emotion research is that, according to him, Meyer (1956) argued so influentially against the meaningfulness of behavioral measures, that "a whole generation of researchers followed his advice to concentrate directly on the analysis of musical structures…" (p. 110). A further challenge concerning harmony perception specifically is that – in addition to harmony – countless other musical parameters (e.g., mode, tempo, rhythm, volume, pitch, timbre, intonation, melodic contour etc.) convey emotions in music. The perceived emotions rise from the sum of all these distinct parts, and the separation of these components artificially in an empirical research setting is challenging to say the least (see e.g., Kaminska & Woolf, 2000). Hence, research on the perception of emotions in music has so far been mainly focusing on the comparison between a few essential musical features such as tempo, pitch height, the major/minor mode distinction, and their order of importance (for a summary, see e.g., Gabrielsson & Lindström, 2010).

As Parncutt and Hair (2011) aptly put it, "harmony is an experience that lies at the interface between sensation and emotion" (p. 161). So far, the focus of research with regard to vertical harmony perception has undoubtedly been more on the sensation side, as the question of consonance/dissonance has received considerably more scholarly attention than emotion perception (e.g., Bidelman & Krishnan, 2011; Cook, 1999; Motte-Haber, 1971; Roberts, 1986). The current work aims to systematically map both of these domains and to shed light on the question of how single isolated chords are perceived across a large and heterogeneous pool of listeners in terms of both perceived emotions (including the associated concept of *preference*) and psychoacoustic qualities. The goal is to investigate whether single isolated chords can convey emotions beyond *basic emotions* (basic emotions typically referring to happiness, sadness, anger, and fear in the field of music psychology [see Juslin, 2013]), in this case the major-happy/minor-sad distinction. This particular distinction carries a stable, conventional, emotional charge in Western musical culture (Crowder, 1984). A related aim is to examine whether there are systematic patterns to be found in how inversions, register and timbre affect chord perception.

As in contemporary music research, both theory and empiricism play significant roles (Honing, 2011), the current work gathers both empirical data on how single chords are perceived, and deciphers this gathered data theoretically. Parncutt and Hair (2011) suggest that while both music theory and cognitive music psychology aim to understand musical structure, they have different methods and different specific goals in doing so. They propose that most recent literature on the topic has been written either from a theoretical or a psychological viewpoint – the aim of the current dissertation is to incorporate both of these viewpoints in order to fill some of the still evident gaps between music theory and music psychology with regard to the question of how single chords are perceived. The current work aims to deepen our understanding about the perception of emotions and consonance/dissonance in chords as phenomena having roots in both acoustics and culture, and sheds new light on the interaction between these two distinct aspects. This new scientific knowledge can be harnessed for further applications in the fields of, for example, musicology, psychology (emotion research), neuroscience, as well as music therapy.

Scientifically, this work is situated in the multidisciplinary field of music psychology and draws from methods of experimental psychology, psychoacoustics, and musicology. It examines existing theories put forward on emotions conveyed by vertical harmony (e.g., Cooke, 1959), and it presents new empirical data on how listeners actually perceive emotions and psychoacoustic qualities in single chords. New theories are introduced on the basis of the gathered empirical data to account for the perception of single chords. The work utilizes the possibilities of the internet for recruiting a large number of research participants, as well as the possibilities offered by technical computing (MATLAB, MIR toolbox) with regard to the psychoacoustic measurements.

The following three chapters (Chapters 2-4) will provide a theoretical framework for the dissertation, introducing its core concepts respectively in the form of *harmony* (Chapter 2), *emotion* (Chapter 3), and *psychoacoustics* (Chapter 4). Chapters 5-7 will outline the work's *aims* (Chapter 5), *methods* (Chapter 6), and *summaries* of the results (Chapter 7). These are elaborated upon with the original research articles I-III, reprinted after the introductory part. Chapter 8 concludes the work by discussing the *results*, its *implications*, *limitations*, and *future plans* for research.

2 HARMONY

2.1 Definition and History of Harmony

Harmony (derived from the Greek word *harmonia,* originally meaning "fitting together", see Philip, 1966) is the simultaneous combining of notes to produce chords, and successively, to produce chord progressions (Dahlhaus et al., 2009). This harmonic orientation is often seen as one of the major differences between Western and much non-Western music (e.g., Malm, 1996). Despite the etymology of the term *harmony*, the simultaneous combining of notes was probably not a part of musical practice in classical antiquity as *harmonia* referred to the relationship between those notes that constituted the framework of the tonal system (Dahlhaus et al., 2009). However, there is no unanimous consensus on whether the ancient Greek musical practice indeed lacked the concept of simultaneously sounding notes (see e.g., Tenney, 1988), and it has been suggested that even earlier music in ancient Mesopotamia could have already contained harmonies (see Kilmer & Civil, 1986; Kilmer, 1998).

In the Middle Ages the concept of harmony referred to two notes, and in the Renaissance to three notes, sounded simultaneously (Dahlhaus et al., 2009). Those as early as Gaffurius (1496/1972) and Zarlino (1573/1966) discuss three-note harmonies, Zarlino including the concept of *triads* in his writings. According to Taruskin (2005), Zarlino was the first theorist to accept the triad as a consonance and was also the first to decisively make the happy/sad distinction between the major and minor triads. As Parncutt (2012a) points out, the major and minor triads were the most common three pitch classes as early as the 14th and 15th centuries, and have been the most common sonorities in Western music since the 16th century. The concept of the chordal *inversion*, namely the proposition that inversions are different manifestations of the same chord type, was for a long time thought to be the discovery of Jean-Philippe Rameau; however, as Dahlhaus et al. (2009) point out, the concept of the inversion had in fact already been anticipated by several theorists in the 17th and early 18th centuries (e.g., Lippius, 1612/1977). Seventh chords as

independent units (used without preparation) came into Western music in the early 17th century in the form of the dominant seventh chord (paving the way for tonality), its introduction often being credited to Claudio Monteverdi (see e.g., Chew, 1989).

2.2 Horizontal vs. Vertical Harmony

It is crucial to distinguish between the *vertical* and *horizontal* dimensions of harmony. *Vertical harmony* refers to the perception of a chord – "the simultaneous sounding of three or more notes" (Bigand et al., 1996, p. 125). Single chords are arguably the smallest building blocks of music that retain emotional information (Bakker & Martin, 2015), although even individual scale degrees are associated with distinct affective qualia when heard successively (Huron, 2006). Psychoacoustically, chords are perceived as single acoustic objects rather than as multiple tones (Bregman, 1994). As Dahlhaus et al. (2009) point out, the conception of a chord as a single unit is governed by the phenomenon of psychoacoustic *fusion* (for definition, see section 4.1.2 of this work). *Horizontal harmony* in turn refers to the successive coincidence of notes (harmonic progressions). Horizontal harmony's emotional effects have been studied empirically more comprehensively than vertical harmony's, by for example Grewe et al. (2007, 2009), Koelsch and Friederici (2003), Sloboda (1991), and Webster and Weir (2005). The current work offers new insight into horizontal harmony's emotional effects as well, since single chords can be regarded as the smallest components of harmony's horizontal dimension (Aldwell & Schachter, 1989).

While a single chord is the basic unit of harmony, harmony and voice leading in practice are in constant interaction. As Persichetti (1978, p. 189) points out: "when melodies sound together chords are formed, and when chords follow each other melodic motion is involved…there is seldom pure harmony or counterpoint for they are deeply involved with each other…even the most isolated chord is full of melodic potential." Even though it is widely held in music theory that chords have musical significance only in relation to other chords (e.g., Hindemith, 1937), single chords seem to have a strong tie with emotional connotations even when presented by themselves – without a musical or tonal context (see e.g., Bakker & Martin, 2015; Heinlein, 1928; Kastner & Crowder, 1990; Pallesen et al., 2005).

3 EMOTION

3.1 Emotion Research

As Fehr and Russell (1984) famously put it, "everyone knows what an emotion is until asked to give a definition" (p. 464). Sloboda and Juslin (2010) concur by suggesting that "emotions are difficult to define and measure, let alone explain" (p. 74). In research, the underlying structure of emotions is usually approached in two distinct ways: with the *categorical* or the *dimensional* approach. According to the categorical approach, emotions are perceived as categories that can be distinguished. This approach includes the concept of *basic emotions* (e.g., happiness, sadness, fear, anger, disgust), which presumes that a limited number of innate and universal emotion categories exist from which other emotional states can be derived (see e.g. Ekman, 1992; Lazarus, 1991). Dimensional theories in turn conceptualize emotions based on their placement along affective dimensions (Sloboda & Juslin, 2010). For example, Russell's (1980) widely used two-dimensional *circumplex model* consists of a circular structure around the dimensions of *pleasure* and *arousal*. As Sloboda and Juslin (2010) suggest, the circumplex model captures two important aspects of emotion, namely that they vary in their degree of similarity, and that some emotions can be conceived as bipolar. Another often applied model in emotion research is the three-dimensional model of affect by Schimmack and Grob (2000). This model attempts to capture the core affects using the three bipolar dimensions of *valence* (intrinsic attractiveness vs. aversiveness), *energy arousal*, and *tension arousal*. The advantage of the dimensional approach is that it separates effectively blended or mixed emotions (Eerola & Vuoskoski, 2011), which are typical for music (Zentner et al., 2008).

3.2 Music and Emotion

The precise definition of what emotions are in regard to music is notoriously problematic as well, "even if there is agreement over their general characteristics and subcomponents" (Eerola et al., 2012, p. 50). Both the discrete and dimensional approaches have been used in music and emotion studies, and both have been criticized for not capturing the richness of emotions conveyed by music (Zentner & Eerola, 2010). Zentner et al. (2008) have proposed a music-specific emotion model called the *Geneva Emotional Music Scales (GEMS)*. GEMS comprises 9 emotion scales: 1) *wonder*, 2) *transcendence*, 3) *tenderness*, 4) *nostalgia*, 5) *peacefulness*, 6) *power*, 7) *joyful activation*, 8) *tension*, and 9) *sadness*. This model is derived from confirmatory factor analyses of ratings of emotions evoked by various genres of music (Zentner & Eerola, 2010). The current work harnesses various emotion models, as the focus is not only on basic emotions such as happiness and sadness, but also on complex, mixed emotions such as nostalgia/longing (see e.g., Juslin & Laukka, 2004). Zentner et al. (2008) suggest that musical emotions tend to occur in a blended manner, and that these blended or mixed emotions can have features of both positive and negative qualities – "nostalgia" being a good example of an emotion encompassing a variety of closely related terms, including "wistfulness" and "longing". In the GEMS model (Zentner et al., 2008) further terms associated with nostalgia include *sentimental*, *dreamy*, and *melancholic*. It is not surprising that scholars have labeled this emotion with a dual label, i.e., "nostalgia/longing" (e.g., Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008). To simplify the terminology, the current work will label this complex and blended emotion as nostalgia to encompass the most common variants, such as nostalgia, longing, and wistfulness.

The emotion models used in this work include the three-dimensional model (Schimmack & Grob, 2000), the *GEMS* (Zentner et al., 2008), and the *Uppsala 15-item Scale for Measuring Emotional Reactions to Music* (Internet 1, n.d., as used by e.g., Juslin et al., 2008).

3.2.1 Emotion Induction Mechanisms of Music

Juslin and Västfjäll (2008, see also Juslin et al., 2010) propose six underlying mechanisms to account for music's ability to induce emotions in listeners, and these are of interest also in the current context of emotion perception, as emotion induction and perception can sometimes be closely intertwined (see section 3.2.2 of this work). 1) *Brain stem reflex* refers to a process whereby an emotion is induced by music because fundamental acoustical characteristics of the music are taken by the brain stem to signal a potentially important and urgent event (e.g., loudness, speed). 2) *Evaluative conditioning* refers to a process whereby an emotion is induced by a piece of music because this stimulus has been repeatedly paired with other positive or negative stimuli. 3) *Emotional contagion* refers to a process whereby an emotion is induced by a piece of music

because the listener perceives the emotional expression of the music, thereby "mimicking" this expression internally. 4) *Visual imagery* refers to a process whereby an emotion is induced because the listener conjures up visual images while listening to the music. 5) *Episodic memory* refers to a process whereby an emotion is induced in a listener because the music evokes a memory of a particular event in the listener's life. Finally, 6) *Musical expectancy* refers to a process whereby an emotion is induced in a listener because specific features of the music violate, delay, or confirm the listener's expectations about the continuation of the music; this mechanism was first proposed by Meyer (1956). Juslin et al. (2010) later added an additional mechanism to the list: 7) *Cognitive appraisal* is related to an evaluation of music on various dimensions in relation to current goals/plans of the listener.

3.2.2 Emotion Induction vs. Emotion Perception

As mentioned previously, it is possible to distinguish between *emotion induction* and *emotion perception* when discussing music and emotions. However, previous empirical research has not always been careful to distinguish between these two different ways in which emotions are conveyed through music (Sloboda and Juslin, 2010). Also Gabrielsson (2002) notes that neither researchers nor research subjects always observe this distinction and might confuse perceived emotions with felt emotions. When discussing the emotional qualities of single isolated chords, the phenomenon in question is most likely *emotion perception*. Juslin and Sloboda (2010b, p. 10) describe this term being "used to refer to all instances where a listener perceives or recognizes emotions in music (e.g., 'a sad expression'), without necessarily feeling an emotion him- or herself." Gabrielsson (2002) suggests that emotion perception and induction can take place simultaneously, and emotion perception does not necessarily lead to emotion induction. As Vuoskoski (2012) remarks, the border between felt and perceived emotion is blurred, and the relationship between the two is somewhat complicated. In the framework of the current work's empirical experiments the participants were specifically instructed to evaluate emotions *conveyed* or *expressed* by the chords, instead of reporting their *induced* emotions, to make sure no confusion emerges.

3.3 Chords and Emotions

According to Shiba and Nemoto (2004, p. 307) "the brain has a very basic common mechanism to associate sounds (chords, in particular) with emotion," and according to studies by Koelsch et al. (2006) and Dellacherie et al. (2009) this can be seen for example in the way the perception of harsh dissonance activates the amygdala (two almond-shaped groups of nuclei located deep and medially within the temporal lobes of the brain, specifically performing a role in emotional reactions). Moreover, the major-happy minor-sad distinction has

been empirically demonstrated to survive de-contextualization, also in the form of single chords (e.g., Crowder, 1985; Heinlein, 1928; Kastner & Crowder, 1990; Marin et al., 2015; McDermott et al., 2010; Pallesen et al., 2005), and this major-minor distinction can be traced on a neural level as well. Pallesen et al. (2005) had both musicians and non-musicians listen to major, minor, and dissonant musical chords while their blood-oxygen-level dependent (BOLD) brain responses were registered using functional magnetic resonance imaging. In both of these listening groups, minor and dissonant chords, compared to major chords, elicited enhanced responses in several emotion-related brain areas during passive listening. Pallesen and colleagues concluded that these results indicate that 1) neural processing in emotion-related brain areas is activated by single chords, 2) emotion processing is enhanced in the absence of cognitive requirements, and 3) musicians and non-musicians do not differ in their neural responses to single musical chords during passive listening. An event-related potential (ERP) study by Bakker and Martin (2015) also suggests that musical chords possess emotional connotations that can be processed as early as 200 milliseconds even by inexpert listeners. Bakker and Martin concluded that major and minor chords have deeply connected emotional meanings, rather than superficially attributed ones, indicating that minor triads possess negative emotional connotations and major triads possess positive emotional connotations.

Although some assume these distinct emotional characterizations of chords to be exclusively culturally learned (e.g., Cazden, 1980; Lundin, 1947), others have posited that they are directly linked to psychoacoustic properties (e.g., Helmholtz, 1895/1980; Rameau 1722/1971; Terhardt, 1974), whilst intermediate positions have also been proposed (e.g., Cook & Fujisawa, 2006; Crowder, 1984; Juslin & Scherer, 2005). As Crowder (1984, p. 10) puts it when discussing the positive valence of the major triad in Western musical culture,

> "something about the properties of musical sounds, perhaps something related to the partials, could have first tipped the affective scales in favor of the major triad, perhaps well back in the history of Western musical practices when the harmonic vocabulary was quite restricted. Then, subsequently, the affective connotations established this way might have been perpetuated through sheer brainwashing."

This intermediate position might well explain the strong affective associations of single chords, even though recent research suggests that even the perception of acoustics (consonance/dissonance) might be more strongly affected by culture (familiarity) than has been previously thought (see Chapter 4 of this work).

As a way of describing how single chords might convey distinct emotions (encompassing not only basic emotions but also complex, mixed emotions), the current work considers cultural, music-theoretical, and psychoacoustic explanations, as well as their possible interactions. To preface these explanations, a probable physical mapping that underlies these proposed explanations are outlined next.

3.3.1 Mapping Between Physical Properties and Affect States

Connections between the emotional expressiveness of physical sounds and underlying physiological states have been posited at least since Spencer (1857), implying that different emotions cause physiological changes that alter vocal expression. This physiological state explanation (Scherer, 1986) accounts for emotions expressed in speech, which in turn bears on musically communicated emotions as well. Juslin and Laukka (2003) have shown that there are strong parallels between vocal and musical expressions of basic emotions (e.g., happiness and sadness). Most of these connections relate to amplitude, tempo/speech rate, and timbre, but there are also links to be found between certain intervals and emotional states as well. For instance, according to Bowling et al. (2010), the spectra of major intervals are more similar to spectra found in excited speech, whereas the spectra of minor intervals are more similar to the spectra of subdued speech. Also, Curtis and Bharucha (2010) propose that the minor third occurs in the pitch contour of speech conveying sadness. Similarly, Huron (2008) has shown that small melodic intervals are more prevalent in sad than happy music, and demonstrated that this feature is directly related to the possible interval sizes available in scales (Huron & Davis, 2012). In general, connections between intervals (both vertical and horizontal) and emotional expression have been found in several empirical studies (e.g., Costa et al., 2000; Cousineau, et al., 2012; Krantz et al., 2004; Maher, 1980; Oelmann & Laeng, 2009), showing that the minor and the major second, and the minor and the major seventh are typically the most displeasing intervals, possessing the most negative valence, with the major seventh also correlating with sadness ratings (e.g., Krantz et al., 2004). The underlying reason why these particular intervals seem to be effective at conveying negative valence may also be related to the amount of dissonance they contain (see Chapter 4 of this work).

3.3.2 Learning/Conditioning

From a psychological perspective, all perception depends on learning (Gibson, 1969), and conventions arguably play a crucial role in the perception of emotions conveyed by vertical harmony as well. Meyer (1956) for example calls a simultaneous group of sounds which lead the listener to expect a more or less probable consequent event a "sound term", suggesting that the dominant seventh chord for instance yields a strong expectation to hear the tonic chord, even when heard in isolation rather than in the context of an actual music passage. Moreover, there is also the possibility that the emotional connotations of certain chords are learned through exposure to their use in specific contexts (e.g. film music and program music). Peretz (2010) for example suggests that "among adults, there is robust evidence that emotional responses are modulated by experience" (p. 103) and that "the unconscious affective influence of prior exposure to music may account for a vast array of phenomena" (p. 104).

These phenomena include, for instance, the emotional distinction between the major and minor mode. Joy and sadness are the most reliably recognized

emotions in Western music (Haack, 1980) and this seems to be reflected in the prevalent major/minor distinction as well. According to Meyer (1956), "communicative behavior tends to become conventionalized for the sake of more efficient communication, so the musical communication of moods and sentiments tends to become standardized" (p. 267). Curiously, Kastner and Crowder (1990) have shown that children as young as three years old can reliably point to drawings of happy and sad faces, respectively, in response to the same tunes played in major or minor keys. Bonetti and Costa (2017) also studied the association of major–minor stimuli with expressions of happiness and sadness, starting with 4-year-old children. Intriguingly, the associations between major-mode and happiness, and between minor-mode and sadness increased from 58% at the age of 4, to 61% at the age of 5, 72% at the age of 6, and 92% in adults.

With regard to specifically single chords, Kastner et al. (1991) found no preference for major triads over minor triads among six-month-old infants using a preferential looking paradigm, and propose that the major/minor emotional connotations might indeed be socially transmitted. On the other hand, even newborn infants' auditory systems are reportedly sensitive to Western music chord categories (Virtala, et al., 2013). Using event-related potentials (ERPs), Virtala and colleagues demonstrated that newborn infants are sensitive to both dissonant and minor chords, but not to inverted major chords in the context of consonant root major chords.

Historically, the origin of the major-happy/minor-sad association dates back to the 14th century and is still disputed (see e.g., Crowder, 1984; Parncutt, 2014b). Parncutt (2012a) points out that the major-happy/minor-sad association may be absent in historical or non-Western traditions that are not based on triadic harmony, but also reminds that the basis of the major/minor emotional distinction is not necessarily only in arbitrary associations, echoing the view of Crowder (1984) discussed previously. Parncutt (2012a, 2014b) sees that the major mode is perceived as a standard form as opposed to the minor mode because music in major keys is more common in Western music, and that this is in turn would be due to the major triad's closer similarity to the harmonic series – hence the major triad being more consonant than the minor triad. This latter view was also suggested by, for example, Helmholtz (1895/1980), Schenker (1906), and Schoenberg (1922/1990). Cross-cultural studies that could shed further light on the origins of the major/minor affective distinction have been inconclusive so far, and leave a lot to be desired with regard to experimental design and scientific rigor (see e.g., Fritz et al., 2009).

3.3.3 Intrinsic Emotional Meaning Built Into Tonality

Learning, however, is not the only possible explanation for why chords might effectively mediate emotional connotations. It has also been suggested that vertical harmony may convey emotions beyond the binary major-happy/minor-sad distinction (Cooke, 1959; Meyer, 1956). For example, Meyer (1956, p. 164) proposes that augmented and diminished triads produce

emotional ambiguity because of their "intervallic equidistance", an even spacing between the tones in the chord. He sees that these chords are identified with affectivity and are often "used to express intense emotion, apprehension, and anxiety." Cooke's (1959) semantic approach implies that tonal relations affect not only horizontal harmony, but also its vertical equivalent as well. For example, he sees that the seventh tone in the major seventh chord is "longing" to the tonic triad (Cooke proposes that the longing effect of the major seventh is present when added specifically to the tonic triad), his view suggesting that vertical harmony is able to create emotional meaning *iconically* in a Peircean sense, that is, conveying the actual emotion of nostalgia/longing by resemblance or imitation. Cooke meticulously explains the nostalgic or longing effect of the major seventh chord by proposing that the major seventh interval's

> "…tension in relation to the triad is a semitonal one upwards to the tonic, so that when it is exposed in relation to the major triad, the 'longing for pleasure' it evokes is so violent as to be almost painful. It is, moreover, a longing for pleasure in a context of finality, aiming at the tonic…" (p. 76).

Like Cooke, Huron (2006, p. 144) also takes notice of the leading tone's distinctive quale, attributing it a "strong sense of precariousness or instability mixed with some urgency and accompanied by feelings of yearning or aspiring upward."

The possible interaction between the learning aspect and Cooke's (1959) proposal of certain chord's emotional properties arising from tonal relations is also something to be considered. The major seventh chord's nostalgic connotations might also arise from a combination of these two distinct aspects with the possibility that this emotional association stems from an abundant exposure of the leading tone's tendency to resolve on the tonic triad in a tonal context (curiously, Cooke neither discusses the emotional effects of the subdominant major seventh chord in a major scale setting, in which the chord's seventh tone is not the leading tone, nor the major seventh chords present in the harmonic and melodic minor scales). In a sense the major seventh chord could thus be seen as "frozen tonal motion" or as a "voice leading still", regardless of whether it actually is in a tonal context or has a tonal function. The dissonance in the major seventh chord could suggest a need to resolve without actually resolving – the major seventh could thus also be labeled a "sound term", like the dominant seventh chord in Meyer's (1956) terminology. Interestingly, Toch (1948, p. 22) proposes that imaginary motion gives meaning to audible symbols, referring to vertical harmony as "arrested motion". The notion that the effects of intervals depend on their relationships to the tonic and other stable pitches in the scale is present in many studies. Krumhansl (1990, p. 18) for example suggests that "a tonal context designates one particular tone as most central" and that "the other tones all have functions specified with respect to this tone…" The cognitive theories of Lerdahl (1988) and Krumhansl (1990) suggest that listeners, regardless of musical sophistication, possess implicit knowledge of tonal hierarchies. It is important to remember, however, that the major

seventh chord is used much more freely and also more often in jazz/pop than in Western classical music, and its emotional connotation is thus not necessarily tied to voice leading conventions of the classical tradition. As Everett (2008, p. 200) points out, the major seventh chord appears most typically on scale degrees I and IV diatonically, but also on many other degrees chromatically, "particularly in soft, breezy jazz contexts".

3.3.4 Clashing Conventions

Cooke's (1959) semantic theorizing offers one possible explanation as to how the major seventh chord might convey the emotion of nostalgia/longing in music. Although Cooke's notion is rooted in tonality and therefore pertinent to horizontal harmony, the findings of the current work's Study I suggest that this effect is present in a single major seventh chord as well – without a tonal or musical context. Cooke's theory, however, seems to have several shortcomings. First, if the additional tones would indeed create *iconic* tension in relation to the (tonic) major triad as Cooke suggests, then why, one might ask, is the dominant seventh chord conveying this particular emotion quite ineffectively, according to the results of Study I in the current work? After all, Cooke remarks that just as the major seventh is longing upwards to the tonic, the minor seventh is accordingly drawn downwards to the dominant. If the (tonic) major seventh chord's nostalgia stems from "tension" and the leading tone's aspiration towards the tonic, it is hardly corroborating his theory that in the dominant seventh chord's case, these same attributes do not seem to convey nostalgia in any effective way. It is noteworthy that the dominant seventh chord conveyed considerably less *nostalgia/longing* than the major seventh chord, rather more *interest/expectancy* and *tension* according to the results of Study I. Second, Cooke's theory also seems illogical when considering the case of the minor-major seventh chord (minor triad plus major seventh). Cooke's theory *per se* would certainly imply that the leading tone would be "longing" to the tonic in the minor-major seventh chord as well; after all, if horizontal harmony would indeed affect chord perception in the way Cooke proposes, the leading or aspiring "quale" of the seventh tone would surely be learned from the harmonic or (ascending) melodic minor scale as equally well as from the major scale, when imposed upon the tonic triad. Intuitively, the minor-major seventh chord would not convey nostalgia in any effective way because of the chord's tonal dissonance (Johnson-Laird et al., 2012) and high amount of both psychoacoustic roughness and inharmonicity (see Chapter 4 of the current work), resulting in a rather sinister and dark sonority. As Cooke's (1959) semantic theory does not seem to comprehensively account for the major seventh chord's ability to convey the emotion of nostalgia/longing, Study II proposes a new theory to account for this phenomenon entitled *clashing conventions*.

Juslin (2013) proposes that listeners' interpretations of emotions in music tend to gravitate towards basic categories and that basic emotions (e.g., happiness, sadness) are at the core of human emotions. In the major seventh

chord's case, one could argue that because these basic emotions are so prominent, they might create subtler affective nuances and convey mixed emotions when overlapping or being present concurrently in the chord. Juslin (2013) proposes that according to many emotion researchers, "mixed emotions" are founded on basic emotions that involve "blends" of emotions. In light of the major triad's conventional role as the "norm" of positive valence (e.g., Meyer, 1956; Parncutt, 2012a), one could consider how additional tones may alter its valence and emotional meaning, this time contemplated from another perspective than Cooke's (1959) suggestion of "iconic" meaning arising from tonal tension in relation to the tonic major triad, which attributes the leading tone a special "affective quale" (cf. Huron, 2006). As the minor second and the major seventh intervals have been shown empirically to score high on the dimensions of sadness and negative valence (e.g., Krantz et al., 2004), these particular intervals could be seen as "obscuring" the positive valence of the major triad, although not "obliterating" it altogether.

In other words, the "clashing" of two highly conventionalized indices in Western musical culture (the major triad as an index of happiness/joy, and the dissonant intervals of the minor second/major seventh as indices of negative valence and melancholy/sadness) could create new emotional meaning that is perceived as the complex emotion of nostalgia/longing. Hence, both positive and negative emotions might be concurrently conveyed by the major seventh chord, creating a sort of "affective dissonance" which in turn is perceived as the bittersweet emotion of nostalgia/longing. The proposed *clashing conventions* explanation is compatible with many analytical descriptions of nostalgia that combine happiness/joy and melancholy/sadness. On an aesthetic level, several definitions of nostalgia have intriguing parallels with this explanation. Batcho (2007), for example, suggests that conflict is inherent in the nostalgic experience, and that "theories that emphasize the bittersweet quality of nostalgic sentiment attribute the bitter side to the realization of the irretrievability of the past and the accompanying sense of irrecoverable loss" (p. 375). Nostalgia is also seen as a yearning for an idealized past (Hirsch, 1992). It is interesting to speculate about the major triad being the "idealized" item, the norm of positive valence which is altered or "obscured" by the sad and negative intervals of the minor second or the major seventh, which are also the sharpest dissonances among dyads (Hutchinson & Knopoff, 1979; Kameoka & Kuriyagawa, 1969; Malmberg, 1918). Also, Werman (1977) sees nostalgia as "wistful pleasure, a joy tinged with sadness" (p. 393). Again, the analogy of the major triad representing happiness/joy, while the minor second and its inversion – the major seventh – representing the tinge of melancholy/sadness is striking. Of course, far from being a completely "fixed" and "lexical" meaning of nostalgia and longing automatically, the major seventh chord is of course subordinate to psychophysical parameters and context as well, just as the major and minor triads with regard to "happiness" and "sadness", respectively (Gabrielsson & Lindström 2010).

4 PSYCHOACOUSTICS

Psychoacoustics is a subdiscipline of psychophysics dedicated to sound and hearing (Parncutt, 2012b), and is "commonly understood as the systematic, quantitative, empirical study of relationships between physical sound parameters and corresponding experiences, or between objective and subjective descriptions of sound" (Parncutt, 2004, p. 1). The following sections describe some of the key psychoacoustic concepts that contribute to the perception of single chords, and particularly to the sensation of consonance/dissonance.

4.1 Consonance and Dissonance

The contrast between consonance and dissonance is a crucial feature of Western music, with its possible origins already having been investigated by the ancient Greeks (see Cazden, 1980; Parncutt & Hair, 2011). Tramo et al. (2001) point out that there is considerable agreement over the notion that consonant means *harmonious*, *agreeable*, and *stable*, while dissonant, in turn, means *disagreeable*, *unpleasant*, and *in need of resolution*. As Parncutt (1989) puts it, "musical sounds are consonant if they are perceived to 'sound well' with each other (con sonare)", and suggests that "chords are consonant if they contain no dissonant intervals" (p. 56). Aesthetic responses to consonance are surmised to have both biological and acoustic roots, and the debate over which prevails represents a classical nature vs. nurture arrangement. Zentner and Kagan (1998) for example propose that the preferential bias for consonance could be innate, basing this view on their finding that infants are biologically prepared to treat consonance as more pleasant than dissonance. Similar observations have been made by Crowder et al. (1991), and Trainor and Heinmiller (1998). Also, Masataka (2006) suggests that infants' preference of consonance over dissonance is present from birth, and is independent of any specific prenatal or early postnatal experience. However, Plantinga and Trehub (2014) later challenged infants' innate preference for consonance. In their study, six-month-old infants failed to listen longer to consonant stimuli (assumed to be a sign of preference) than dissonant

stimuli. However, after three minutes of exposure to consonant or dissonant stimuli the infants listened longer to the familiar stimulus, whether consonant or dissonant. Plantinga and Trehub suggest that this effect of short-term exposure is consistent with the view that it is in fact familiarity that underlies the origin of the Western preference for consonant intervals.

Other arguments have also been made in favor of the view that the concept of consonance/dissonance is completely culture dependent and unique to Western musical culture (e.g., Cazden, 1980; Lundin, 1947). Maher and Jairazbhoy (1975) noted that musical intervals classed as extreme dissonances in Western music appear to be used more freely in Indian classical music, and Maher (1976) found in an empirical setting Indian listeners to indeed oppose less to dissonance than Canadian listeners. Curiously, a recent study by McDermott et al. (2016) suggests that consonance preferences are absent in cultures sufficiently isolated from Western music. McDermott and colleagues propose that consonance/dissonance preferences are presumably determined by exposure to musical harmony, suggesting that a preference for consonance is unlikely to be innate. On the other hand, cross-cultural evidence also exists corroborating the view of the universality of consonance/dissonance perception with regard to the question of preference/pleasantness, at least to some extent (see Butler, 1968; Fritz et al. 2009). Curiously, a preference for consonance has also been found in animals: for example, in albino rats (Fannin & Braud, 1971), in an infant chimpanzee (Sugimoto et al., 2010), and in domestic chicks (Chiandetti & Vallortigara, 2011). It is too early to say anything definite about the nature vs. nurture question with regard to single chord perception, even though it is highly likely that enculturation indeed affects the perception of consonance/dissonance in addition to the biological substrate of roughness (beating).

In addition to the debate on its origins, consonance/dissonance is a semantically loaded and a problematic concept, volatile also in a historical context. As Tenney (1988, p. 1) puts it: "there is surely nothing in the language of discourse about music that is more burdened with purely semantic problems than are the terms *consonance and dissonance*." Hindemith (1937, p. 85) also attends to this problem:

> "the two concepts have never been completely explained, and for a thousand years the definitions have varied. At first thirds were dissonant; later they became consonant. A distinction was made between perfect and imperfect consonances. The wide use of seventh-chords has made the major second and the minor seventh almost consonant to our ears."

Consonance/dissonance can be divided into two subcategories: single isolated intervals and chords represent *sensory consonance/dissonance* (psychoacoustics), while consonance/dissonance in chords and intervals while being part of a musical context is referred to as *musical consonance/dissonance* or *musical acoustics* (e.g., Krumhansl, 1990; Terhardt, 1984; Zwicker & Fastl, 1990). The interaction between these two distinct levels is also noteworthy: as Bigand et al. (1996)

point out, a chord can be very dissonant while having a stable tonal function (for example the minor-major seventh chord that ends some jazz pieces), and conversely a consonant chord can have an unstable tonal function (for example a modulating dominant chord).

The difference between consonance and dissonance is also distinguishable on a neuroscientific level. Shapira Lots and Stone (2008) point out that there may be more than one neural source that contributes to the perception of consonance and dissonance, and neural correlates of consonance/dissonance perception have been found in the brainstem and the auditory cortex (Bidelman & Krishnan, 2011). Moreover, consonant and dissonant chords have been found to activate different regions of the brain to varying extents (e.g., Fishman et al., 2001; Minati et al., 2009), with the amygdala for example showing activation related to harsh dissonance (Dellacherie et al., 2009; Koelsch et al., 2006).

Zwicker and Fastl (1990, p. 313) point out three psychoacoustic factors that specifically contribute to sensory consonance/dissonance: (a) *roughness*, (b) *sharpness*, and (c) *tonalness* (in contrast to noisiness). Parncutt (2012a) suggests that the overall consonance/dissonance of Western sonorities is in fact based on a *combination* of *roughness*, *harmonicity*, and *familiarity*. The following sections will define each of these three concepts, as well as other psychoacoustic phenomena affecting the perception of single chords.

4.1.1 Roughness

It is widely held that sensory dissonance arises from the beating of frequency components (e.g., Hutchinson & Knopoff, 1978; Kameoka & Kuriyagawa, 1969). According to McDermott et al. (2010, p. 1) "beating occurs whenever two sinusoids of differing frequency are combined", which in turn creates the sound quality of roughness that listeners typically perceive as unpleasant. The sensation of roughness has a biological substrate, as beating occurs at the level of the basilar membrane in the inner ear (Peretz, 2010). The effect of roughness is seen as prevalent in dissonant, but not in consonant musical chords (e.g., Hutchinson & Knopoff, 1978; Plomp & Levelt, 1965). Bigand et al. (1996) propose that chords with minor thirds have systematically greater roughness than chords with major thirds (provided that voicing, register, and spectral content are held constant similarly), and that chords with sevenths have greater roughness than chords without sevenths. In addition to roughness, *sharpness* is held as another form of sensory dissonance, caused by energy at high frequencies (see Aures, 1985a, 1985b).

Some studies, however, indicate that the concept of roughness may not be sufficient to explain dissonance perception in dyads (e.g., Bidelman & Krishnan, 2009; Itoh et al., 2010). Moreover, as Johnson-Laird et al. (2012) point out, roughness in itself fails to predict the relative dissonance of even some of the most common triad chords. McDermott et al. (2016) suggest that the Western notion of dissonance may be distinct from actual psychoacoustic roughness, but in turn closely related to the concept of *inharmonicity* (see section 4.1.2 of this work). They also suggest that although an aversion to roughness seems to be

present cross-culturally, it might not necessarily be related to the question of consonance and dissonance, presumably because musical sounds are in practice not very rough.

4.1.2 Harmonicity

Harmonicity is "the extent that the sonority's audible spectrum corresponds to a harmonic series" (Parncutt, 2014a, p. 972, see Figure 1). For example, a major triad has high harmonicity because it is "more similar to the harmonic series as it exists among the audible partials of everyday harmonic complex tones such as voiced speech sounds" (Parncutt, 2012a, p. 130). Studies by McDermott et al. (2010) and Cousineau et al. (2012) suggest that harmonicity plays an important role in the perception of consonance/dissonance, possibly an even more important one than roughness. McDermott et al. (2010, p. 2) propose that "consonant chords derive their pleasantness not from the absence of beating, but rather from their similarity to single notes with harmonic spectra." The study by McDermott and colleagues curiously indicates that harmonicity preferences correlate with musical expertise, suggesting that exposure to music amplifies preferences for harmonic frequencies because of their musical importance. The concept of harmonicity is also timbre dependent. As Deutsch (2013, p. 186) points out, "string and wind instruments produce tones whose partials are harmonic, or close to harmonic, and these give rise to strongly fused pitch impressions." In contrast, the small departures from perfect harmonicity are important to, for example, the piano sound (Pierce, 1999).

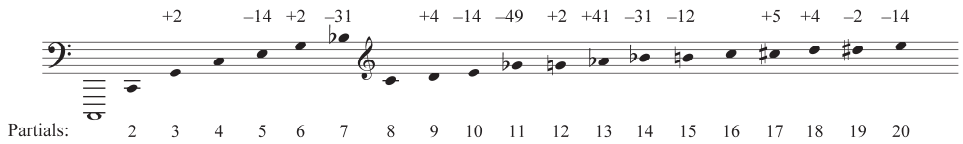

FIGURE 1 The harmonic series in musical notation. Numbers below the notes indicate the ordering of the partials in the harmonic series. Numbers above the notes indicate the difference from equal temperament as calculated in cents (see e.g., Hulen, 2006).

Fusion is the tendency for many simultaneous sounds to be heard as one (Parncutt & Hair, 2011). According to the *tonal fusion model* (Stumpf, 1890; 1898), the degree to which two or more tones perceptually fuse into a single auditory object affects the perception of consonance. Stumpf's theory has also received empirical support (DeWitt & Crowder, 1987). As Marin et al. (2015) point out, the *tonal fusion model* is comparable to current models of consonance according to which the more the partials of pitch combinations match a single harmonic series (harmonicity), the higher the degree of perceived consonance (McDermott et al., 2010; Plack, 2010). Parncutt and Hair (2011) suggest that when the ear perceives a harmonic complex tone such as a voiced speech sound

or musical tone, it distinguishes the frequencies of several partials, but usually hears only one pitch. They argue that this same phenomenon can explain why musical chords blend into one sound. Moreover, they propose that since major and minor triads fuse well, this effect may explain their general prevalence in Western music. Parncutt (2004) also proposes that in the Western music of the 18th and 19th centuries dominant seventh chords were more prevalent than major seventh and minor seventh chords, which in turn were more prevalent than diminished and half-diminished seventh chords (based on the data of Eberlein, 1994). Parncutt suggests that the principle of fusion favors the dominant seventh chord because all its tones correspond to lower elements of the harmonic series, and sees that the principle of fusion may have dominated the principle of roughness in determining the prevalence of sonorities in the common practice period.

4.1.3 Familiarity

As Marin et al. (2015) point out, studies by Guernsey (1928) and McLachlan et al. (2013) have challenged both roughness and tonal fusion models as explanations for the perception of consonance/dissonance, suggesting instead that *familiarity* with commonly used musical chords underlies consonance perception. McLachlan et al. (2013) suggest that music training increases familiarity for commonly used chords, and previous research indicates a decrease in dissonance associated with music training for common chords (e.g., Brattico et al., 2009; McDermott et al., 2010).

Contemplating the issue from a historical point of view, Parncutt and Hair (2011, p. 146) point out that "sounds that are initially perceived as dissonant (such as an unprepared dominant seventh chord in Monteverdi) can be perceived as consonant if heard often enough, suggesting that exposure, familiarity and learning are an important aspect of consonance…" They remind, however, that mere exposure cannot cause any kind or degree of dissonance to become consonant (cf. McLachlan et al., 2013), suggesting that atonal music of recent decades includes dissonant sonorities that may never be heard as consonant, no matter how often they are heard. As Marin et al. (2015) aptly point out, familiarity may indeed play a role in judgements of consonance, but the perception of consonance/dissonance is arguably determined by a convergence of both learned and psychoacoustic factors, including roughness and harmonicity.

4.1.4 Tonal Dissonance

Johnson-Laird et al. (2012) propose that the perception of dissonance can be explained with what they call a "dual-process theory of dissonance". They suggest that dissonance actually results from a combination of both sensory and tonal dissonance, the latter meaning "a consequence of high-level cognitive processes that rely on a tacit knowledge of the principles of tonality" (p. 24). This slightly differs from the concept of musical consonance/dissonance

discussed previously, because in musical consonance/dissonance chords are in an actual musical context, while tonal dissonance deals with the *hypothetical* context of chords which nonetheless seem to affect how they are perceived when presented by themselves. Johnson-Laird et al. (2012) propose that tonal dissonance depends on the scales in which the chords can occur: chords occurring in a major scale should theoretically be less dissonant than chords occurring only in a minor scale, which in turn should be less dissonant than chords occurring in neither sort of scale. Moreover, they suggest that "chords that are consistent with a major triad are more consonant than chords that are not consistent with a major triad…hence, a chord of a seventh, such as GBDF, is consistent with a major triad (GBD) because the seventh, F, occurs in a major scale in which the triad also occurs (the scale of C major), whereas a chord, such as GBDEb, is not consistent with a major triad because the added note does not occur in a major scale containing the major triad" (p. 24). Similarly, Tramo et al. (2001, pp. 112–113) also suggest that "implicit knowledge about the hierarchical relationships of pitches in a given tonal system is likely to exert cognitive influences on the degree to which intervals and chords sound consonant or dissonant, even when they are heard in isolation."

To summarize, arguably many or even all of these distinct psychoacoustic phenomena discussed above might contribute to the sensation of consonance/dissonance in isolated dyads and chords (see also Marin et al., 2015; Parncutt, 2014b; Parncutt & Hair, 2011). The effect of these phenomena naturally depends on other perceptual qualities as well (e.g., loudness, timbre). As an example of the synergetic interaction between some of these psychoacoustic phenomena, Parncutt (2012a) argues that for instance the major and minor triads are the most consonant sonorities of three pitch classes because they include perfect fifths (high harmonicity and fusion), but no seconds (low roughness). Moreover, these chords became familiar to Western ears over an extended historical period (familiarity). The role of these distinct psychoacoustic phenomena on single chord perception will be further elaborated in Chapter 7, based on the empirical data of Studies I and III.

5 AIMS OF THE DISSERTATION

The primary aim of this work is to understand the relationship between psychoacoustic properties of single chords and the emotion they express for Western listeners. Moreover, the work's goal is to investigate the subjective liking/preference of chords, as liking/preference is arguably the most common affective reaction to musical stimuli (see e.g., Brattico & Jacobsen, 2009), and according to many empirical experiments both familiarity and complexity with regard to stimuli affect preference in music (for an overview, see Hargreaves & North, 2010).

Although the power of chords to convey distinct emotions has been acknowledged theoretically (e.g., Cooke, 1959; Meyer, 1956; Rameau, 1722/1971), few empirical studies have attempted to study the precise nature of these emotions, or to investigate whether these emotions encompass also complex emotions (e.g., nostalgia/longing, see e.g., Cooke, 1959, Everett, 2008) in addition to basic emotions (e.g., happiness and sadness). Such information is not only relevant to the fields of music psychology, musicology, and psychoacoustics, but it could also tell us more about how emotions are perceived in the human mind in general. Related aims of the work include the mapping of how inversions, register and timbre affect chord perception, the evaluation of the fittingness of some of the existing, standard emotion scales used in music and emotion research to encompass also single chord perception, and the investigation of the possible role of demographic and musical background factors on how single chords are perceived. Furthermore, as most studies on vertical harmony perception so far have used only dyad and triad chords as stimuli, the current work introduces a more versatile chord palette not only in the form of triads, but also tetrads, pentads, and hexachords, to raise the work's ecological validity. The chords' acoustic qualities will also be analyzed objectively in terms of psychoacoustic properties to complement the subjective self-reports.

Studies I and II focus exclusively on the emotion perception of single chords and how psychoacoustics affects it. Study I uses a 9-item emotion scale, based on previous studies on music and emotions in order to map the emotion

perception of single chords. It investigates the applicability of the dimensions used in standard emotion scales to chord perception, including the *GEMS* (Zentner et al., 2008), the *Uppsala 15-item Scale for Measuring Emotional Reactions to Music* (Internet 1, n.d., used by e.g., Juslin et al., 2008), and the three-dimensional model (Schimmack & Grob, 2000). Moreover, Study I aims to explain differences in emotion perception for a wide range of chords in terms of musical conventions, timbre, and demographic/musical background. Using the data of Study I, Study II focuses on the perception of the complex, mixed emotion of nostalgia/longing in certain chord types. It critically examines Cooke's theory (1959) specifically with regard to the capacity of the major seventh chord to convey nostalgia/longing to listeners, and provides a competing theory to account for this. Study III focuses on the perceived psychoacoustic qualities of single chords, and aims to replicate the results of Study I concerning the perception of triadic inversions, as well as the question of preference depending on the amount of consonance/dissonance present in the chords. The motivation for the replication is to see whether these findings are consistent with the methodological improvements applied to Study III: compared to Study I, Study III contains the randomization of chord roots across stimuli, the addition of new chord types, pitch height as an experimental variable, and also consonance ratings as a dependent variable.

It has been hypothesized that the relationship between dissonance (complexity) and preference usually takes the form of an inverted-U curve (Parncutt, 1989), meaning that for relatively low degrees of dissonance, preference increases with increasing dissonance, while for relatively high degrees, preference decreases with increasing dissonance. Study III investigates the role of both objective and subjective consonance/dissonance in chord perception with regard to preference. It disentangles the roles of psychoacoustic roughness, harmonicity, and sharpness in the perception of consonance/dissonance. In addition to the inverted-U theory, Study III investigates the possible role of *aggregate dyadic consonance* (Huron, 1994), i.e., the sum of the consonances of all interval classes within a chord with regard to the perception of preference in single chords.

6 METHODS

The methods and stimuli used in the three studies are reported in detail in the original research articles I-III. The empirical data used in the current work were collected with two large-scale listening experiments where participants evaluated single isolated chords on pre-chosen emotion dimensions. In addition, information about the participants' musical background, music preferences, current mood, type of audio device used, and demographic background (gender, age, nationality, education) were gathered. Statistical methods were used in the data analysis, and the stimuli were analyzed in terms of various psychoacoustic properties (roughness, harmonicity, sharpness, brightness, irregularity, spectral flux, and log attack time).

6.1 Listening Experiments

The two listening experiments (Studies I and III) were conducted online. The experiment interfaces were programmed with JavaScript, made specifically for the purpose of the experiments. The language of the experiments and their instructions was exclusively English. The participants for the study were recruited through the internet with the aim of attracting both musicians and non-musicians, and having a heterogeneous, large, and international participant pool (for a review of the benefits of this strategy, see Honing & Ladinig, 2008 and Honing & Reips, 2008). The experiments were advertised through social media (Facebook, LinkedIn) and on many emailing lists of different universities and music institutions around the world. As an incentive, gift cards to Amazon.com were offered in two respective draws for all participants who provided their email addresses with their responses for this purpose.

6.1.1 Emotion Scales and Stimuli

Both experiments (Studies I and III) used pre-chosen scales to assess perceived emotional qualities conveyed by single chords. The reason for choosing pre-chosen (closed set of terms instead of open answers) scales is that these scales are based on previous empirical research specifically on music and emotions (e.g., Eerola & Vuoskoski, 2011; Juslin & Laukka, 2004; Juslin et al., 2008;). In music and emotion studies, open answers are typically analyzed to be comprised of a few underlying emotion dimensions (see Zentner et al., 2008), and providing an open answer possibility in the current experiments' framework would have arguably yielded a huge number of adjectives not directly related to the emotional connotations of the presented chords (cf. Kuusi, 2009).

In Study I, the participants were asked to rate triads (major, minor, diminished, and augmented) and seventh chords (dominant seventh, minor seventh, and major seventh) with inversions on a 9-item emotion scale. The experiment presented some of the most commonly used triads and seventh chords in the Western classical and popular idioms; the amount of chord types was deliberately kept relatively low to keep the experiment short and thus interesting for the participants. Even though the basic emotion categories (e.g., happiness, sadness) are probably the easiest to recognize and communicate in music (e.g., Juslin & Laukka, 2003; Peretz, 2010), the study also applied complex emotions in order to reflect the subtler variations of perceived emotions in single chords. As Zentner et al. (2008) point out, musical emotions tend to occur in a blended manner: blended or mixed emotions can have features of both positive and negative qualities, for example nostalgia. The first three bipolar dimensions of the 9-item scale were adopted from Schimmack and Grob (2000). The other five unipolar dimensions were chosen on the basis of the *GEMS*, which is "derived from confirmatory factor analyses of ratings of emotions evoked by various genres of music" (Zentner & Eerola, 2010, p. 206), and the *Uppsala 15-item Scale for Measuring Emotional Reactions to Music* (Internet 1, n.d., used by e.g., Juslin et al., 2008). The dimensions were chosen based on hypotheses of what kind of emotions single chords could theoretically be able to convey, guided by previous literature (e.g., Cooke, 1959; Meyer, 1956). The resulting 9-item emotion scale consisted of the following dimensions: 1) *Valence*, 2) *Tension*, 3) *Energy*, 4) *Nostalgia/longing*, 5) *Melancholy/sadness*, 6) *Interest/expectancy*, 7) *Happiness/joy*, and 8) *Tenderness*. As an extra dimension, the participants' *liking/preference* for each chord was also measured to map the subjective preference for chords, independent of the dimension of valence. As Juslin (2011) points out, 'emotion' and 'preference' tend to influence each other, but are partly independent phenomena nonetheless - in the case of single chords a participant might perceive that a dissonant chord is negative in valence, but prefer it nevertheless.

The mixed, complex emotion of *nostalgia/longing* was included in the 9-item scale, because nostalgia is reportedly a common emotion in music, both as

felt and *perceived* emotions (Juslin & Laukka, 2004). Moreover, also Zentner et al. (2008) identify nostalgia's prominent role as a musical emotion in the *GEMS*. The terms "nostalgia" and "longing" are often used interchangeably in music literature (e.g., Cooke, 1959; Mitchell, 2002), and they are also linked in the double term "nostalgia/longing" which is used as part of the *Uppsala 15-item Scale for Measuring Emotional Reactions to Music* inventory (Internet 1, n.d.). The dimension of *interest/expectancy* was included because it is also considered to be an important general feature with regard to music and emotions (Juslin et al., 2008). Out of the five basic musical emotions (happiness, sadness, tenderness, fear, anger), fear and anger were omitted, as fear has been considered an example of a musical emotion arising mainly from conditioning (Zentner & Eerola, 2010), while anger may have more to do with psychophysical cues present in an actual musical context (tempo, dynamics, phrasing) than with single isolated chords. The first three bipolar dimensions were rated on a Likert scale ranging from 1 to 5. With *valence*, the bipolar extremes were 1 = negative, 5 = positive. With *tension*, the extremes were 1 = relaxed, 5 = tense, and with *energy*, the extremes were 1 = low, 5 = high. The six unipolar dimensions were rated on a Likert scale ranging from 1 to 5 (1 = very slightly or not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely). The participants were given the chance to listen to each chord as many times as they wished. The ordering of the chords was randomized for each participant.

In Study III, the participants were asked to rate major and minor triads with inversions, and selected tetrads (added sixth and minor seventh), pentads (dominant ninth, minor ninth, major ninth, pentatonic, and Neapolitan pentachord), and hexachords (dominant seventh sharp eleventh and diatonic hexachord) in root positions on a 5-item scale. The first three bipolar dimensions of the five scales were again adopted from Schimmack and Grob (2000) in the form of *valence*, *energy*, and *tension*. The fourth applied dimension was consonance (used in studies by e.g., Bidelman & Krishnan, 2011; Roberts, 1986) in order to capture the participants' subjective perception of consonance and dissonance in a given chord. The fifth dimension measured the participants' subjective preference for each chord. The last two dimensions were chosen in order to investigate the amount of overlap between perceived consonance and preference with regard to single chord perception (cf. the inverted U-theory, e.g., Berlyne, 1971; Parncutt, 1989). This study omitted secondary emotions used in Study I (such as *nostalgia/longing*), as the focus was on the perception of consonance/dissonance.

The participants were asked to rate each chord on the presented 5-item scale. The five dimensions were rated on a Likert scale ranging from 1 to 7. With *valence*, the bipolar extremes were 1 = negative and 7 = positive. With *tension*, the extremes were 1 = relaxed and 7 = tense, and with *energy*, the extremes were 1 = low and 7 = high. With *consonance*, the extremes were 1 = rough and 7 = smooth, these two poles having been used extensively in previous research literature (e.g., Bregman, 1994; van de Geer et al., 1962; Parncutt & Hair, 2011). For *preference*, the applied poles were 1 = low and

7 = high. The participants were given the chance to listen each chord as many times as they wished. The ordering of the chords, the chords' roots (across two octaves), as well as the ordering of the five dimensions were randomized for each participant.

6.1.2 Musical Sophistication

In both experiments (Studies I and III) the participants' musical sophistication was measured with the *Ollen Musical Sophistication Index* (Ollen, 2006), a 10-item questionnaire yielding a score for every participants' musical sophistication between 0 and 999, the score of 500 being the threshold between a participant being less or more musically sophisticated (see Marcs Auditory Laboratories, Internet 2, n.d.). For compatibility with a large number of studies conducted on music perception, the current work uses this threshold as the divider between a "musician" and a "non-musician". The distribution among these groups was 36.8% musicians and 63.2% non-musicians in Study I, and 52.7% musicians and 47.3% non-musicians in Study III. In Study I, non-musicians were divided into lower (OMSI score < 250, N = 116) and higher score (250 ≤ OMSI score < 500, N = 54) groups respectively. The musicians were also divided into lower (500 ≤ OMSI score < 750, N = 35) and higher (OMSI score ≥ 750, N = 64) score groups respectively.

6.1.3 Music Preferences

In Study III, music preferences were inferred from the ratings of 13 genres that were recoded into four meta-genres suggested by Rentfrow and Gosling (2003) based on hierarchical cluster analysis, clustering the participants into four cluster groups according to the similarity of their music preferences. Each participant belonged to one of these clusters, labeled as *Reflective or Complex* (n = 215), *Intense or Rebellious* (n = 86), *Upbeat or Conventional* (n = 76), and *Energetic or Rhythmic* (n = 33).

6.1.4 Mood Measurement

In Study I, the affective mood of the participants was measured with the Positive and Negative Affect Schedule-measurement (PANAS; Watson, Clark, & Tellegen, 1988) to see if the participants' mood affected chord perception. The PANAS measurement is a tool applied to measure participants' positive and negative affect by using 5 positive and 5 negative adjectives. The participants were asked to rate each adjective on a scale from 1 to 5 (1 = very slightly or not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely).

6.2 Psychoacoustic Measurements

All of the current work's studies (I, II and III) included psychoacoustic analyses of the applied stimuli. In Study I, a set of core features were extracted that were implemented in past timbre and emotion studies (see Eerola et al., 2012). These features comprised roughness, brightness, irregularity, spectral flux, and log attack time, and were extracted using MIR toolbox (version 1.5, Lartillot & Toiviainen, 2007). The roughness estimation used the psychoacoustic model by Vassilakis (2001), brightness was calculated as the balance between high- and low-frequency spectral energy (cut-off set to 1000Hz), and irregularity quantified the variation of the successive peaks in the spectrum using Jensen's algorithm (1999). Spectral flux was computed by calculating the Euclidean distance between successive frames, and finally, the log attack time was simply estimated from the onset of shape (from the valley to peak time, see Krimphoff et al., 1994). For the first four measures, the analysis frame was 42ms in duration, with 50% frame overlap.

In Study II, the psychoacoustic predictions were estimated by first creating all possible four-tone chords within an octave (resulting in 536 separate chords, discounting inversions). These chords (and one three-tone chord, C-Eb-G, as a reference) were implemented as a combination of four equally loud fundamentals that were transformed into complex sounds with Shepard spectra using MIDI toolbox (Eerola & Toiviainen, 2003). These sounds were in turn analyzed with MIR toolbox (version 1.5) for harmonicity (Jensen, 1999) and roughness (Vassilakis, 2001).

In Study III, selected features were extracted using MIR toolbox (version 1.6.1, Lartillot et al., 2008) and custom MATLAB functions based on prior studies. These were (a) harmonicity (Jensen, 1999), (b) roughness (Vassilakis, 2001), and (c) sharpness that is related to the high-frequency content of the sound (Zwicker & Zwicker, 1991).

7 RESULTS

The results (including tables and figures) of the three studies are elaborately reported in the original research articles I-III.

7.1 Chord Types and Emotions

In Study I, nine different scales were constructed for statistical analysis by aggregating each participant's 28 chord ratings on each of the nine dimensions. The rating scales' internal consistency was measured with Cronbach's alpha (range .76−.92). It is noteworthy how such reduced stimuli as these single chords yielded such high internal consistency: the obtained Cronbach's alphas are comparable to previous empirical studies on music and emotions where complete musical excerpts were used as stimuli (Zentner et al., 2008; Eerola & Vuoskoski, 2011). Correlations between the nine variables were calculated. The strongest correlations were found between the dimensions of *melancholy/sadness* and *nostalgia/longing* (.74), and between *happiness/joy* and *valence* (.56). However, none of the dimensions demonstrated complete overlap. Study I demonstrated that certain chord types (the minor triad, the minor seventh, and especially the major seventh) conveyed the complex, mixed emotion of *nostalgia/longing* to listeners effectively, especially when played in the strings timbre. It is noteworthy how, in the major seventh chord's case, the mixed emotion of *nostalgia/longing* captured the chord's affective quality better than either of the two basic emotions of *happiness/joy* and *melancholy/sadness*. When played in the string timbre, the modal nostalgia rating of both the minor triad and the major seventh chord was 4 ("Quite a bit") on the 5-point Likert scale, in each chord position. That is, a typical listener perceived "quite a bit" of *nostalgia/longing* in these particular chords. Intriguingly, the major seventh chord's third inversion's mean rating was highest on the dimension of *nostalgia/longing* of all the given dimensions when played on the strings, implying that this particular chord conveys the complex, mixed emotion of nostalgia/longing *par excellence*.

With regard to the overall suitability of the given dimensions to the chord evaluations, an interesting tendency is that in Study I, the dimension of *happiness/joy* received surprisingly low mean ratings and was used mainly for the major triad. Also the dimension of *tenderness* received quite low mean ratings in aggregate, suggesting that this dimension is not very apposite with respect to single chord perception. On the basis of the responses, "positive valence" seems to describe the emotional quality conveyed by single chords more accurately than the dimension of *happiness/joy*. The results also suggest that mildly dissonant chords in terms of both sensory (i.e., chords containing dissonant intervals) as well as musical consonance/dissonance (see e.g., Révész, 1954) seem to be more preferred than consonant chords, across two distinct timbres (piano and strings).

In Study III, the rating scales' internal consistency was again measured with Cronbach's alpha, also showing high internal consistency (range .80 − .87). Correlations between the five variables were calculated: the strongest correlations were found between the dimensions of *tension* and *consonance* (−.97), *tension* and *preference* (−.79), and between *tension* and *energy* (.78). While there was evident overlap between the dimensions of *valence*, *consonance*, and *preference*, this overlap was not complete (cf. the virtually complete negative correlation between *tension* and *consonance*) and suggests that perceived consonance does not automatically result in more perceived valence and preference in single chord perception. Study III suggests that mildly dissonant chords are more preferred than maximally consonant chords across both expert and inexpert listeners, replicating the results of Study I in this regard.

7.2 Inversions

In Study I, the role of inversions with regard to emotion ratings was compared with separate repeated ANOVAs. A two-way ANOVA examined the Inversion (root or any inversion) and Chord Type (triad or seventh) for each emotion dimension, which resulted in significant main effects of Inversion for the dimensions of *valence*, *energy*, *tension*, *interest/expectancy*, and *happiness/joy*. Moreover, all emotion dimensions exhibited significant interaction between Inversion and Chord Type, suggesting that the inversions made a particularly strong contribution to the ratings in the major and minor triads. With the major triad the tendency was that *valence*, *tension*, and *energy* all exhibited a pattern of increasing ratings from root through first inversion to second inversion on both timbres. A similar pattern also occurred for *interest/expectancy* and *happiness/joy*. This tendency was similar with the minor triad, but the effect was much weaker.

In Study III, the results on the perception of triadic inversions were mostly in line with Study I: *energy* and *tension* exhibited significant main effects with the ratings growing from root through first inversion to second inversion across both major and minor triads, and the scale of *preference* did not exhibit a

significant main effect with regard to inversions. The scale of *consonance/dissonance* exhibited a significant main effect with an opposing pattern when compared with the scales of *tension* and *energy*: in both major and minor triads, perceived consonance decreased from root through first inversion to second inversion. With regard to the major triad, the least amount of perceived consonance in the chords' second inversion is notably in line with musical convention (see e.g., Randel, 2003), and also with the classic counterpoint rule according to which the fourth is dissonant if formed with the bass (i.e., unsupported by lower notes); intriguingly, however, this pattern of perception was not influenced by musical sophistication. Strikingly, both musicians and non-musicians distinguished triadic inversions similarly on the dimensions of *energy*, *tension*, and *consonance/dissonance*. To the author's best knowledge, the current work is the first to empirically demonstrate this trend. Curiously, Kuusi (2009) also found differences in how listeners perceive triadic inversions, but attributed these differences to the fact that all participants in her study were trained musicians. While non-musicians arguably could not consciously discriminate between the intervallic orderings of the chords (cf. Kuusi, 2015), it is striking that they nonetheless perceived the inversions similarly to musicians on the aforementioned dimensions. Of course, theoretically the possibility exists that this effect is due to pitch height rather than inversion (the pitch height increasing with first and second inversions of the triads), however there was no systematic pattern to be found between ratings and median pitch heights of the chords measured as an additional part of the data analysis for Study III.

The only notable difference between the results of Study I and Study III with regard to the triadic inversions was on the scale of *valence*. While exhibiting a statistically significant main effect, this significance was considerably smaller in Study III and showcased a different pattern. The randomization of roots dissolved virtually any perceived difference between the major triad's inversions, and the minor triad's first inversion was perceived as containing the most amount of positive valence; in the data of Study I, the difference between the minor triad's first and second inversions with regard to valence was negligible. It is noteworthy how the minor triad's first inversion has a major third above the bass and might hence sound somewhat "major", this could explain its higher amount of positive valence in the results of Study III.

7.3 Register

In Study III two distinct registers were applied for the stimuli. All chords were transposed with a randomization across two octaves (± 5 semitones around C4 and C5). To estimate whether the ratings across the chords and register exhibited any differences, a two-way repeated-measures analysis of variance was carried out for all five dimensions with the Chord Type and Register (Low and High) as the two within-subject factors. Chord Type consisted of the 11

main categories of chords in which the triadic inversions were collapsed into the main types of triad chords. Overall, the effect sizes for Register were considerably smaller than for Chord Type. The effect size for *valence* across Register was conspicuously small, and this finding is in line with Parncutt (2014b) who proposes that pitch height in music is normally associated with arousal, not valence. Parncutt also suggests that music with a high average pitch tends to contain more energy than music with a low average pitch; this seems to hold true also for single chord perception as chords in the higher register were perceived as more energetic and tense than chords in the lower register. Ilie and Thompson (2006) also found that tension grew with pitch height in an empirical setting using actual musical excerpts as stimuli; this same effect is evident in single chord perception as well.

7.4 Timbre

Study I applied two distinct timbres for the stimuli: piano and strings. To estimate whether the emotion ratings across the chords and timbre differed statistically, a two-way repeated-measures analysis of variance was carried out for each emotion dimension with the Chord Type and Timbre (Piano and Strings) as the two within-subject factors. The most prominent differences of timbre in emotion dimension ratings were found in the dimensions of *nostalgia/longing* and *melancholy/sadness*, where the strings timbre had significantly higher mean ratings than the piano. Respectively, the piano timbre had higher mean ratings on the dimension of *happiness/joy*. The strings' highly emotional quality may arise through the mechanism of emotional contagion (as discussed in section 3.2.1 of this work), in this case also with regard to emotion *perception* as opposed to *induction*. According to Juslin and Västfjäll (2008, see also Juslin and Timmers, 2010) the voice-like aspects of music (for example the timbre of the violin) are very effective at expressing emotions to listeners, leading the listener to mimic the perceived emotion internally.

7.5 Psychoacoustics

In Study I the acoustic properties of the chords did not correlate with the majority of the applied emotion dimensions. The only exceptions were *nostalgia/longing* and *tenderness*, which exhibited significant correlations with brightness ($r = .46$ and .42), roughness ($r = .50$ and .38), flux ($r = .54$ and .48), and attack time ($r = .50$ and .42, for all $df = 26$, $p<.05$).

Study II argued that the amount of harmonicity might affect the amount of *nostalgia/longing* perceived in certain chord types. The current work's proposed *clashing conventions* theory (see section 3.3.4 of this work) predicts that a lower amount of harmonicity might correlate with a higher amount of perceived

nostalgia/longing, other psychoacoustic parameters (roughness, tonal dissonance) being largely equal.

In Study III roughness and sharpness correlated statistically significantly with the dimensions of *tension*, *energy*, and *consonance*. Both roughness and sharpness correlated positively with *tension* and especially with *energy*, while negatively with *consonance*. The lesser amount of perceived consonance in chords played in the higher register could be explained with the effect of sharpness, as chords in the lower register contained significantly more objective roughness compared with chords in the higher register, despite being subjectively perceived as more consonant. This finding is in line with the notion that sharpness is another form of sensory dissonance in addition to roughness, caused by energy at high frequencies (see Aures, 1985a, 1985b).

With regard to the difference between objective roughness and subjective dissonance, the results of Study III offer some intriguing further insights. The diatonic hexachord is theoretically more rough than the dominant seventh sharp eleventh chord, and the pentatonic chord more rough than the Neapolitan pentachord. The ordering of these chords' subjective dissonance, however, was exactly the opposite: the pentatonic chord was perceived as significantly more consonant compared with the Neapolitan pentachord, and the diatonic hexachord more consonant compared with the dominant seventh sharp eleventh chord. This finding suggests that enculturation in the form of *tonal dissonance* (as discussed in section 4.1.4 of this work, see also Johnson-Laird et al., 2012) indeed also affects judgments of sensory consonance (single chords) and not only musical consonance (cf. Minati et al., 2009). Similarly, the found difference between the perceived amount of consonance in the common pitch class set of the added sixth and the minor seventh chords is noteworthy – the added sixth chord was perceived as more dissonant than the minor seventh chord. An interesting detail is that the added sixth chord was nonetheless perceived as more positive in valence than the minor seventh chord. This could imply that the added sixth is more affiliated with the major triad because of its root when compared to the minor seventh, and again suggests that enculturation affects single chord perception in addition to psychoacoustics.

7.5.1 Inverted-U Theory and Aggregate Dyadic Consonance

As harmonicity, roughness, and sharpness were not individually statistically significantly correlated with *preference*, Study III outlined the theoretical possibility of how aggregate dyadic consonance (Huron, 1994), i.e., the sum of the consonances of all interval classes within a chord, might affect perceived preference in single chords in addition to the inverted-U theory (see Parncutt, 1989). Parncutt (1989, p. 54) takes notice of the fact that the relationship between consonance and preference is not necessarily always linear by suggesting that "...chord progressions in Western music tend to be preferred to unaccompanied melodies, even though single complex tones are more consonant than chords." Parncutt proposes that the relationship between dissonance (complexity) and preference usually takes the form of an inverted-U curve: "for relatively low

degrees of dissonance, preference increases with increasing dissonance, while for relatively high degrees, preference decreases with increasing dissonance" (p. 57). While the inverted-U hypothesis offers one possible explanation for why mild dissonance is preferred over consonance in single chord perception, it does not seem to be comprehensive. For example, it cannot account for the fact that according to the data of Study I, the dominant seventh, and in Study III the dominant ninth chords, were less preferred than the major and minor triads, which according to the inverted-U hypothesis as such should be the other way around – the dominant seventh being somewhere in between the extremes of consonance and dissonance when considering a large number of possible chord sonorities (cf. Huron, 1994). The two theories (inverted-U and aggregate dyadic consonance) combined seem to provide a good fit for explaining the general preference of mild dissonance over consonance in single chord perception. The most preferred chords contain a moderately high amount of aggregate dyadic consonance (Figure 2). For example, the high amount of objective roughness and subjective dissonance in the pentatonic chord should theoretically predict a much higher aversion – its moderately high aggregate dyadic consonance might explain why the chord is relatively preferred nonetheless. It is noteworthy in Figure 2 how the preference ratings dramatically drop between the pentatonic and the hexatonic chords; it could be argued that there is a critical threshold of roughness, which cannot be crossed, in order for a single chord to be subjectively preferred.

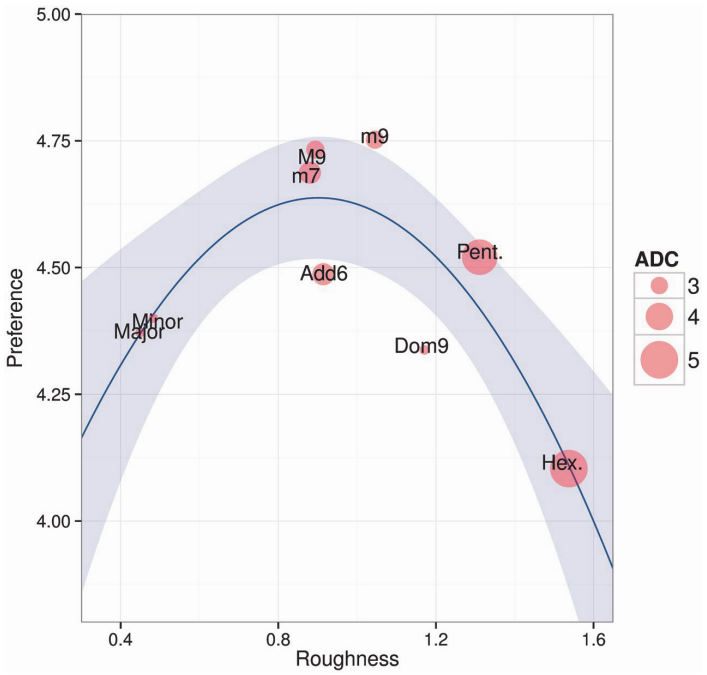

FIGURE 2 Preference, Roughness, and Aggregate Dyadic Consonance values across Chord Types, excluding chords containing tonal dissonance.

7.6 Demographic and Musical Background

In Study I, the difference in ratings according to musical sophistication was quite small as revealed by effect sizes, and concerned only the dimensions of *interest/expectancy* and *liking/preference*. Still, participants with higher levels of musical sophistication evaluated the chords more consistently at the extremes of the scales, according to musical convention. For example, musicians rated the major seventh chord as having more tension and the major triad as having less tension when compared to non-musicians' ratings. All in all, however, the difference in emotion perception according to musical sophistication was surprisingly negligible. Concerning differences related to demographic background variables, nationality exhibited relatively few and minor differences, again limited to the dimensions of *nostalgia/longing* and *melancholy/sadness*. These emotions were perhaps the most culturally loaded terms among the used dimensions in Study I (see Hepper et al., 2014).

According to the results of Study III, those with higher musical expertise (and also those belonging to the "*Reflective or Complex*" musical preference group) perceived the chords as more positive in valence, more consonant, and also preferred the chords more. This finding is in line with the notion that familiarity affects the perception of chords (Guernsey, 1928; McLachlan et al., 2013), as well as the perception of consonance/dissonance in general (Cazden, 1972; Heyduk, 1975). However, it is important to keep in mind that non-musicians may also be highly familiar with various musical chords through incidental exposure and active listening, even if they lack the training to explicitly identify and distinguish chords by name.

While both expert and inexpert listeners preferred mild dissonance over consonance overall, intriguingly the least musically sophisticated listeners liked the maximally consonant major and minor triads most alongside the mildly dissonant minor seventh in both Studies I and III. However, familiarity does not seem to predict preference in the dominant ninth chord's case: it is the only pentad present in major–minor tonality and should thus be more familiar than the other, possibly more exotic, five-note sonorities used in Study III. Despite its familiarity, the dominant ninth was the least preferred pentad after the Neapolitan pentachord. As in Study I, the magnitude of variations according to musical background as revealed by effect sizes was considerably small and negligible in Study III, too.

8 DISCUSSION AND CONCLUSIONS

8.1 Perceived Qualities of Single Chords

The results of this work suggest that single chords are consistently able to convey distinct emotions to listeners, independent of musical or demographic background. Despite chords having musical significance only in relation to other chords (Hindemith, 1937), they seem to contain clear-cut emotional connotations even when presented in isolation, outside a musical or tonal context. The focus of this dissertation was on perceived emotions encompassing not only basic emotions such as happiness and sadness, but also mixed, complex emotions such as nostalgia/longing. The work also mapped the perception of consonance/dissonance and its relation to subjective preference. The results suggest that mild dissonance is preferred over consonance in single chord perception across two distinct timbres (piano and strings), and this tendency is largely independent of musical sophistication. To the best of the author's knowledge, the present work is the first to empirically demonstrate vertical harmony's ability to convey complex emotions (nostalgia/longing) in addition to basic emotions, the tendency of both expert and inexpert listeners to similarly evaluate triadic inversions, and the overall preference for mild dissonance over consonance in single chord perception. The results also curiously imply that chord inversions contribute more to the perception of the major and minor triads than other chord types. Moreover, the results present striking analogies between single chord perception and the perception of musical excerpts: pitch height does not affect valence (Parncutt, 2014b), but in turn affects energy and tension perception (Ilie & Thompson, 2006; Parncutt, 2014b). Also, the emotion scales used in this work's studies show high internal consistency (measured with Cronbach's alpha) that is comparable to previous empirical studies on music and emotions where complete musical excerpts were used as stimuli (Eerola & Vuoskoski, 2011; Zentner et al., 2008).

With regard to musical sophistication, the difference between expert and inexpert listeners in single chord perception is surprisingly negligible. While

both Studies I and III showcased some differences between musicians and non-musicians in chord perception, the magnitude of variations according to musical background was quite small in both studies. Curiously, the effect of musical sophistication on single chord perception does not seem to be as salient as it is on, for example, the perception of tension in short chord sequences (Bigand et al., 1996) or on the perception of emotions conveyed by speech prosody (Thompson et al., 2004). The current work's results are thus in line with the findings of Pallesen et al. (2005) who point out that musicians' ability to recognize and categorize chords in terms of conventional emotional connotations does not necessarily result in an enhanced emotional experience.

8.2 Theoretical Implications of the Results

The current work's finding that single chords also have the ability to convey mixed, complex emotions (nostalgia/longing) is somewhat surprising, as nostalgia/longing is usually held as a musical emotion rising only from extra-musical connotations and conditioning, not intrinsically from the structural features of the music itself (e.g., Barrett et al., 2010; Janata et al., 2007; Wildschut et al., 2006). Of course, the perception of certain chords sounding nostalgic could also be due to learning (e.g., film and program music), as discussed in Chapter 3 of the current work; it is too early to say anything definitive about the mechanisms behind this phenomenon. However, the results are in line with Cooke's semantic theorizing (1959) that the major seventh chord consistently conveys nostalgia and longing in music, with Everett (2008), who discusses the major seventh chord sounding "nostalgic" and "wistful", and with Fleming and Veinus (1958), who discuss the major seventh's capacity to effectively express the emotion of "longing" in music. The current work argues that Cooke (1959) possibly misattributes the major seventh chord's nostalgia to the "longing" of the leading tone (when imposed on specifically the tonic major triad) towards the tonic, and proposes a new theoretical model entitled *clashing conventions* to account for the major seventh chord's capacity to convey the emotion of nostalgia/longing effectively. This theory suggests that both positive and negative emotions might be conveyed by the major seventh chord concurrently, creating "affective dissonance" which in turn is perceived as the mixed emotion of nostalgia/longing. As Krumhansl (2002, p. 45) suggests, there is a possibility that "music imitates the sounds of objects or events with emotional connotations", and this same mechanism could theoretically also account for the major seventh chord's ability to iconically convey the emotion of nostalgia/longing through affective dissonance present in the chord. Hence, the current work raises the possibility that nostalgia in music is not necessarily related exclusively to episodic memory (see Juslin & Västfjäll, 2008), i.e., extramusical connotations, but that it could be conveyed also by vertical harmony, intra-musically.

With regard to the realm of psychoacoustics, the results of the current work suggest that a moderately high amount of roughness in single chords does not automatically result in weaker preference. The negligible role of harmonicity in the perception of single isolated chords in regard to the questions of consonance/dissonance and preference is in line with Mellinger and Mont-Reynaud (1996), who suggest that the relationship between harmonicity and the perception of harmony is not straightforward, and also with Bregman (1994, p. 496) who remarks that "harmonicity may not be critical for chord perception." However, this finding may have to do with the fact that Study III applied only the piano timbre: according to Pierce (1999) the small departures from perfect harmonicity are important to the piano sound – in other words, harmonicity is presumably more salient in non-percussive, steady sounds than in percussive, rapidly fading sounds. However, the results of Study I suggest that while the timbres of piano and strings revealed some differences with regard to emotions conveyed by chords, the overall shape of the results concerning chord types and emotions was still similar. It is possible that harmonicity might in fact be more relevant to perceived consonance/dissonance and preference in *dyad* chords (see Parncutt, 2014b) instead of chords consisting of multiple pitches. While in the results of Study III harmonicity does not seem to offer a comprehensive explanation with regard to the question of perceived consonance/dissonance and preference, Study II proposed the possibility that harmonicity, however, may play a role in conveying the complex, mixed emotion of nostalgia/longing. As this is somewhat paradoxical, it calls for further experiments to thoroughly investigate the role of harmonicity in the perception of simultaneously sounding pitches with regard to complex emotions and perceived consonance/dissonance.

Overall, the results of the current work suggest that single chord perception (sensory consonance/dissonance) is not independent of learning and culture. The concept of tonal dissonance (Johnson-Laird et al., 2012) seems to affect single chord perception, a case in point being the low perceived consonance and preference of the Neapolitan pentachord in Study III. This particular chord was the least preferred sonority and clearly subjectively judged as the most dissonant, despite not objectively being among the roughest chords in the presented stimuli. An interesting example of enculturation possibly affecting single chord perception in the results of the current work is the low preference of the dominant seventh and dominant ninths chords despite their familiarity and high amount of harmonicity. This effect may stem from the presence of the tritone interval present in both chords, this particular interval's avoidance having both psychoacoustic and cultural origins (Parncutt, 1989, 2014a). Curiously, psychoacoustic fusion does not seem to correlate with subjective preference either in the dominant seventh chord's case, even though all of its tones correspond to lower elements of the harmonic series (Parncutt, 2004). All in all, the current work's psychoacoustic analysis suggests an interpretation similar to that of Parncutt (1989), Tramo et al. (2001), and Arthurs (2015) that for chords, pure acoustic explanations may not adequately account

for their perception, and that the phenomenon of consonance/dissonance is a combination of both acoustics and enculturation (Parncutt & Hair, 2011).

8.3 Limitations

As the focus of this work has been exclusively on single chord perception with the aim of keeping the number of confounding variables as low as possible, the work has left many related questions unexplored as of yet. The ecological validity of the stimuli itself is something to be considered: Studies I and III used synthesized samples (albeit high quality), which may have affected the psychoacoustic analysis of the stimuli to some extent and possibly their overall perception. The experiments applied only two distinct timbres altogether, and the chords were exclusively played in close positions which arguably made them more like music theory textbook examples than vertical moments from actual music. Also, the music preferences of the respondents in Study III was assessed with the four-factor structure reported by Rentfrow and Gosling (2003), which has not been entirely replicated with European participants (see Delsing et al., 2008). While the experiments reached a large number of participants from around the world, caution should be exercised when generalizing from this sample, as the represented population was predominantly Western, and those taking the experiment were undoubtedly familiar with Western musical practices. Also, the possible role of music preferences with regard to the perception of seventh chords and emotions could not be answered in the context of the current work, as Study I did not yet map the musical taste of the participants.

With a web-based approach the control over participants is not as rigid as with a lab-based approach. This was a possible setback especially with regard to the participants' audio configurations – however, audio configuration setups did not affect the results in any significant way in the case of Study III where participants were asked to provide self-reports of their used audio devices. While there were some internet connection problems in a few respondents' case and a handful of malicious responses present in the experiments, these cases were successfully weeded out with the aid of effective screening (e.g., the experiment interfaces were programmed to check the amount of time spent on the interface) built into the experimental design. Such cases were evident on the basis of the interfaces' result databases and were removed from the pools at the data analysis stages. All in all, while there are evidently some disadvantages to an internet based research approach, Goslin et al. (2004) and Honing and Ladinig (2008) have also pointed out a number of advantages in Web-based studies. These include, for instance, demographic diversity and the possibility of reaching a large number of intrinsically motivated respondents, positively influencing the ecological validity of the results by allowing respondents to take part in the experiment from their home – an arguably more natural listening environment than the classic laboratory setup.

As the experiments were conducted exclusively in English, the possibility exists that the interpretations of the emotion dimensions varied among the different nationalities. However, those who ended up taking the experiments arguably had a high level of English proficiency, as the instructions and the experiment interfaces were available exclusively in English. Each applied emotion dimension's meaning was also meticulously explained in the experiments. The question of the pre-chosen emotion scales versus the possibility of open answers in the experiments is also something to be considered. While the given dimensions might have guided the participants' evaluations to some extent, this drawback is actually common to all methodologies relying on verbal methods (Zentner & Eerola, 2010). It is highly unlikely that such clear patterns (as evident on the basis of the results) would have arisen coincidentally had a random set of scales and labels been applied – the strength of the original research protocol in Studies I and III lies in the fact that the applied dimensions have been used in a large variety of past studies of emotional expression in music (e.g., Eerola & Vuoskoski, 2011; Juslin & Laukka, 2004; Juslin et al., 2008). While for example the double term "nostalgia/longing" is somewhat robust (encompassing a number of related terms), this umbrella term made it possible to gather data on a level that was delicate enough to showcase clear differences and underlying patterns, but was not so ambiguous so as to create too much diversity resulting in the inability to meaningfully interpret the results. Moreover, with the experiments' applied Likert scales there was always the possibility to rate a chord very low (the lowest position on the Likert scale was "very slightly or not at all") if it absolutely did not seem to fit a certain dimension, a possibility the participants also clearly used if we take for example the "happiness" of the augmented triad in Study I.

With regard to the question of preference in single chords, it is open to debate what the word *preference* actually means and how informative it ultimately is. In the experiments, the participants were asked how much they liked the chords and were reminded that this was a purely subjective question. While it is unclear at this point how much overlap there is for example between the terms *preference* and *pleasantness* with regard to single chord perception, it is noteworthy how the highest internal consistency on any emotion dimension (measured with Cronbach's alpha) in both Studies I (.92) and III (.87) was specifically for the dimension of *liking/preference*. Interestingly, Guernsey (1928) has demonstrated that musicians make a distinction between the concepts of "consonance" and "pleasantness", and the current work suggests that ratings of "preference" are not linear with the amount of perceived consonance either. Strikingly, this pattern of perception also seems to be largely independent of musical sophistication.

8.4 Implications for Future Studies

According to neuroscientific experiments, single chords contain deeply rooted emotional connotations (Bakker & Martin, 2015; Pallesen et al., 2005). The question of whether these emotional associations run deeper than the major-happy minor-sad distinction is yet unclear. As Brattico and Pearce (2013) and Omigie (2015) point out, there is an urgent need for neuroscientific studies on how the brain processes complex musical emotions (e.g., nostalgia), and also subjective preference. As Omigie (2015, p .9) notes, research focusing on the mechanisms by which aesthetic and complex emotions arise would not only be useful to the field of music research, but "such an approach would also be of most use and interest to the emotion research community in general".

Future studies should also disentangle the underlying reasons why triadic inversions differ in perception, and why for example the major triad's second inversion was perceived as the least consonant across both expert and inexpert listeners, according to musical convention. Also, the significant differences found with just two distinct timbres suggests a need for more research on the effect of timbre on chord perception. In addition, the role of timbre with regard to the importance of harmonicity in single chord perception is a crucial question and should be addressed with new experiments. The role of aggregate dyadic consonance as an explanation for why the relationship between the lack of roughness and the amount of preference is not linear should be studied with a higher number of chord sonorities, as the current work's Study III had only nine data points in its model to account for this phenomenon. Moreover, the crucial threshold of maximum roughness in simultaneous pitch combinations resulting in a decline of preference should be investigated. Finally, the effect of tuning (equal temperament vs. just temperament) with regard to the perception of consonance/dissonance and the perception of single chords in general should be investigated, and also the perception of chords in musically richer contexts.

8.5 Concluding Remarks

In actual music, different chords can create different affects depending on musical context, and subjectivity plays a significant role in music perception. However, on the basis of the current work's results, this does not mean that there are no underlying similarities to be found with regard to single chord perception, even within a highly heterogeneous pool of respondents. The work demonstrated that there are indeed clear similarities in the perception of emotions and psychoacoustic qualities in single chords, among a vast number of individuals with quite diverse demographic and musical backgrounds. The found preference for mild dissonance over consonance calls for a re-evaluation and additional research on the relationship between perceived

consonance/dissonance and preference/pleasantness, and the ability of even single chords to convey subtle and complex emotions (nostalgia/longing) in turn is a finding that addresses questions to various research disciplines about how emotions are perceived in the human mind and brain. Research on vertical harmony's emotional connotations is thus not only significant to the disciplines of musicology and psychology (music psychology), but also for the understanding of human emotions in general. The current work's results suggest that the perception of single chords is a delicate, synergetic combination of cultural conventions and psychoacoustic phenomena. To conclude, more empirical experiments are recommended to shed further light on the question of vertical harmony perception, an experience situated at the *interface between sensation and emotion*.

TIIVISTELMÄ (FINNISH SUMMARY)

Soinnut tunnemerkitysten välittäjänä musiikissa

Väitöskirja tarkastelee monitieteistä lähestymistapaa käyttäen vertikaalisen harmonian havainnointia: työssä yhdistyvät psykologinen, musiikkitieteellinen, sekä psykoakustinen näkökulma. Harmonisten tekijöiden emotionaalisen vaikutuksen tutkimus musiikissa on tähän mennessä keskittynyt lähinnä horisontaaliseen harmoniaan vertikaalisen harmonian jäädessä taka-alalle. Työssä tarkastellaan vertikaalista harmoniaa yksittäisten sointujen osalta, ilman musiikillista tai tonaalista kontekstia. Fokuksessa ovat soinnuissa havaitut subjektiiviset tunnemerkitykset sekä objektiivisten psykoakustisten laatujen vaikutukset näihin tunnemerkityksiin.

Väitöskirja sisältää kolme julkaisua, jotka kaikki käsittelevät tutkimusaihetta eri näkökulmista. Julkaisut perustuvat kahteen laajaan empiirisen, kansainväliseen kuuntelukokeeseen, joissa sekä muusikot että ei-muusikot arvioivat sointuja valmiilla emootiodimensioilla. Koemateriaalina toimi tonaalisesta musiikista tuttuja kolmi- ja nelisointuja käännöksineen, sekä harvinaisempia viisi- ja kuusisävelisiä sointuja. Soinnut soitettiin yhteensä kahdella sointivärillä: pianolla ja jousilla. Soinnut myös analysoitiin niiden psykoakustisten laatujen kannalta.

Tulokset osoittavat, että yksittäiset soinnut välittävät tunnemerkityksiä riippumatta kuulijoiden demografisesta tai musiikillisesta taustasta. Nämä tunnemerkitykset eivät limity pelkästään perusemootioihin (esim. ilo ja suru), sillä tulosten perusteella yksittäiset soinnut voivat tehokkaasti välittää monimutkaisiakin tunnemerkityksiä, kuten nostalgiaa ja kaihoa. Miedosti riitasointiset soinnut ovat tulosten perusteella pidetympiä kuin täysin tasasointiset soinnut, ja sekä muusikot että ei-muusikot hahmottavat sointukäännöksiä samansuuntaisesti. Empiirisiin tuloksiin perustuen väitöskirja esittää uusia teoriamalleja selittämään yksittäisten sointujen kykyä välittää monimutkaisia tunnemerkityksiä sekä konsonanssin/dissonanssin havainnointia soinnuissa.

Asiasanat: Sointu, harmonia, vertikaalinen harmonia, emootio, konsonanssi/dissonanssi, psykoakustiikka

REFERENCES

Aldwell, E., & Schachter, C. (1989). *Harmony and Voice Leading*. New York: Harcourt Brace Jovanovich.

Arthurs, Y. (2015). *The creation of consonance: How musical context influences chord perception* (Doctoral dissertation). University of Sheffield.

Aures, W. (1985a). Der sensorische Wohlklang als Funktion psychoakustischer Empfindungsgrößen (Sensory pleasantness as a function of psychoacoustic sensations). *Acustica, 58*, 282−290.

Aures, W. (1985b). Ein Berechnungsverfahren für den sensorischen Wohlklang beliebiger Schallsignale (A procedure for calculating sensory pleasantness of various sounds). *Acustica, 59*, 130−141.

Bakker, D. R., & Martin, F. H. (2015). Musical chords and emotion: Major and minor triads are processed for emotion. *Cognitive, Affective, & Behavioral Neuroscience, 15*, 15−31.

Barrett, F. S., Grimm, K. J., Robins, R. W., Wildschut, T., Sedikides, C., & Janata, P. (2010). Music-evoked nostalgia: Affect, memory, and personality. *American Psychological Association, 10*, 309−403.

Batcho, K. I. (2007). Nostalgia and the emotional tone and contents of song lyrics. *The American Journal of Psychology, 120*, 361−381.

Berlyne, D. E. (1971). *Aesthetics and Psychobiology*. New York: Appleton-Century-Crofts.

Bidelman, G., & Krishnan, A. (2009). Neural correlates of consonance, dissonance, and the hierarchy of musical pitch in the human brainstem. *The Journal of Neuroscience, 29*, 13165−13171.

Bidelman, G., & Krishnan, A. (2011). Brainstem correlates of behavioral and compositional preferences of musical harmony. *Neuroreport, 22*(5), 212−216.

Bigand, E., Parncutt, R., & Lerdahl, J. (1996). Perception of musical tension in short chord sequences: The influence of harmonic function, sensory dissonance, horizontal motion, and musical training. *Perception & Psychophysics, 58*, 125−141.

Bonetti, L., & Costa, M. (2017). Musical mode and visual-spatial cross-modal associations in infants and adults. *Musicae Scientiae*. doi: 10.1177/1029864917705001

Bowling, D. L., Gill, K., Choi, J. D., Prinz, J., & Purves, D. (2010). Major and minor music compared to excited and subdued speech. *Journal of the Acoustical Society of America, 127*, 491−503.

Brattico, E., & Jacobsen, T. (2009). Subjective appraisal of music: Neuroimaging evidence. *Annals of the New York Academy of Sciences, 1169*, 308−317.

Brattico, E., & Pearce, M. T. (2013). The neuroaesthetics of music. *Psychology of Aesthetics, Creativity and the Arts, 7*, 48−61.

Brattico, E., Pallesen, K. J., Varyagina, O., Bailey, C., Anourova, I., Järvenpää, M., Eerola, T., & Tervaniemi, M. (2009). Neural discrimination of

nonprototypical chords in music experts and laymen: an MEG study. *Journal of Cognitive Neuroscience, 21*, 2230−2244.

Bregman, A. S. (1994). *Auditory Scene Analysis: The Perceptual Organization of Sound*. Cambridge, MA: MIT Press.

Butler, J. W., & Daston, P. G. (1968). Musical consonance as musical preference: A cross-cultural study. *Journal of General Psychology, 79*, 129−142.

Cazden, N. (1972). The systematic references of musical consonance response. *International Review of Aesthetics and Sociology of Music, 3*, 217−245.

Cazden, N. (1980). The definition of consonance and dissonance. *International Review of the Aesthetics and Sociology of Music, 11*(2), 123−168.

Chew, G. (1989). The perfections of modern music: Consecutive fifths and tonal coherence in Monteverdi. *Music Analysis, 8*(3), 247−273.

Chiandetti, C., & Vallortigara, G. (2011). Chicks like consonant music. *Psychological Science, 22*(10), 1270−1273.

Cook, N. D. (1999). Explaining harmony: The roles of interval dissonance and chordal tension. *Annals of the New York Academy of Science, 930*, 382−385.

Cook, N. D., & Fujisawa, T. X. (2006). The psychophysics of harmony perception: Harmony is a three tone phenomenon. *Empirical Musicology Review, 1*(2), 106−126.

Cooke, D. (1959). *The Language of Music*. Oxford, UK: Oxford University Press.

Costa, M., Bitti, P., & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music, 28*, 4−22.

Cousineau, M., McDermott, J., & Peretz, I. (2012). The basis of musical consonance as revealed by congenital amusia. *Proceedings of the National Academy of Sciences, 109*, 19858−19863.

Crowder, R. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology, 4*, 3−10.

Crowder, R. (1985). Perception of the major/minor distinction: III. Hedonic, musical, and affective discriminations. *Bulletin of the Psychonomic Society, 23*, 314−316.

Crowder, R., Reznick, J. & Rosenkrantz, S. (1991). Perception of the major/minor distinction: V. Preferences among infants. *Bulletin of the Psychonomic Society, 29*(3), 187−188.

Curtis, M., & Bharucha, J. (2010). The minor third communicates sadness in speech, mirroring its use in music. *Emotion, 10*(3), 335−348.

Dahlhaus, C., Anderson, J., Wilson, C., Cohn, R., & Hyer, B. (2009). *Harmony*. Grove Music Online. Oxford Music Online. Oxford University Press. Retrieved from http://www.oxfordmusiconline.com/subscriber/article/grove/music/50818

Dellacherie, D., Pfeuty, M., Hasboun, D., Lefevre, J., Hugueville, L., Schwartz, D. P., Baulac, M., Adam, C., & Samson, S. (2009). The birth of musical emotion: A depth electrode case study in a human subject with epilepsy. *Annals of the New York Academy of Sciences, 1169*, 336−341.

Delsing, M. J. M. H., Ter Bogt, T. F. M., Engels, R. C. M. E., & Meeus, W. H. J. (2008). Adolescents' music preferences and personality characteristics. *European Journal of Personality, 22*, 109−130.

Deutsch, D. (2013). Grouping mechanisms in music. In D. Deutsch (Ed.), *The psychology of music, 3rd Edition* (pp. 183−248). San Diego: Elsevier.

DeWitt, L., & Crowder, R. (1987). Tonal fusion of consonant musical intervals: The oomph in Stumpf. *Perception & Psychophysics, 41*, 73−84.

Eberlein, R. (1994). *Die Entstehung der tonalen Klangsyntax* [The emergence of tonal-harmonic syntax]. Frankfurt: Lang.

Eerola, T., & Toiviainen, P. (2003). *MIDI toolbox: MATLAB tools for music research*. Jyväskylä, Finland: University of Jyväskylä.

Eerola, T., & Vuoskoski, J. K. (2011). A comparison of the discrete and dimensional models of emotion in music. *Psychology of Music, 29*(1), 18−49.

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and affect dimensions: Evidence from affect and similarity ratings and acoustic correlates of isolated instrument sounds. *Music Perception: An Interdisciplinary Journal, 30*(1), 49−70.

Ekman, P. (1992). An argument for basic emotions. *Cognition & Emotion, 6*, 169−200.

Everett, W. (2008). *The Foundations of Rock: From "Blue Suede Shoes" to "Suite: Judy Blue Eyes"*. New York: Oxford University Press.

Fannin, H., & Braud, W. (1971). Preference for consonant over dissonant tones in the albino rat. *Perceptual and Motor Skills, 32*, 191−193.

Fehr, B., & Russell, J. (1984). Concept of emotion viewed from a prototype perspective. *Journal of Experimental Psychology: General, 113*(3), 464−486.

Fishman, Y. I., Volkov, I. O., Noh, M. D., Garell, P. C., Bakken, H., Arezzo, J. C., Howard, M. A., & Steinschneider, M. (2001). Consonance and dissonance of musical chords: Neural correlates in auditory cortex of monkeys and humans. *Journal of Neurophysiology, 86*(6), 2761−2788.

Fleming, W., & Veinus, A. (1958). *Understanding music: Style, structure, and history*. New York: Holt, Rinehart and Winston.

Frigyesi, J. (1998). *Béla Bartók and Turn-of-the-Century Budapest*. Berkeley: University of California Press.

Fritz, T., Jentschke, S., Gosselin, N., Sammler, D., Peretz, I., Turner, R., Friederici, A., & Koelsch, S. (2009). Universal recognition of three basic emotions in music. *Current Biology, 19*(7), 573−576.

Gabrielsson, A. (2002). Emotion perceived and emotion felt: Same or different? *Musicae Scientiae, Special Issue 2001−2*, 123−147.

Gabrielsson, A., & Lindström, E. (2010). The role of structure in the musical expression of emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 367−400). Oxford, UK: Oxford University Press.

Gaffurius, F. (1496/1972). *Practica Musicae*. Bologna: Forni.

Gagnon, L., & Peretz, I. (2003). Mode and tempo relative contributions to 'happy - sad' judgments in equitone melodies. *Cognition and Emotion, 17*(1), 25−40.

van de Geer, J. P., Levelt, W. J. M., & Plomp, R. (1962). The connotation of musical consonance. *Acta Psychologica 20*, 308−319.

Gibson, E. J. (1969). *Principles of Perceptual Learning and Development*. New York: Appleton-Century-Crofts.

Goldman, R. (1965). *Harmony in Western Music*. New York: W.W. Norton & Company.

Goslin, S. D., Vazire, S., Srivastava, S., & John, O. P. (2004). Should we trust web-based studies? A comparative analysis of six preconceptions about internet questionnaires. *American Psychologist, 59*(2), 93−104.

Grewe, O., Kopiez, R., & Altenmüller, E. (2009). Chills as an indicator of individual emotional peaks. *Annals of the New York Academy of Sciences, 1169*, 351−354.

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007). Listening to music as a recreative process: Physiological, psychological, and psychoacoustical correlates of chills and strong emotions. *Music Perception, 24*(3), 297−314.

Guernsey, M. (1928). The role of consonance and dissonance in music. *The American Journal of Psychology, 40*, 173−204.

Haack, P. (1980). The behavior of music listeners. In D. Hodges (Ed.), *Handbook of music psychology* (pp. 141−182). Lawrence, Kansas: National Association of Music Therapy.

Hargreaves, D. J., & North, A. C. (2010). Experimental aesthetics and liking for music. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 515−546). Oxford, UK: Oxford University Press.

Heinlein, C. P. (1928). The affective characteristics of the major and minor modes in music. *Journal of Comparative Psychology, 8*(2), 101−142.

Helmholtz, H. (1895/1980). *On the Sensations of Tone as a Physiological Basis for the Theory of Music*. Translated by Alexander Ellis. New York: Dover.

Hepper, E. G., Wildschut, T., Sedikides, C., Ritchie, T., Yung, Y.-F., Hansen, N., . . .Zhou X. (2014). Pancultural nostalgia: Prototypical conceptions across cultures. *Emotion, 14*(4), 733−747.

Heyduk, R. G. (1975). Rated preference for musical compositions as it relates to complexity and exposure frequency. *Perception and Psychophysics, 17*, 84−91.

Hindemith, P. (1937). *Craft of Musical Composition, Vol. I*. Translated by Arthur Mendel. New York: Schott Music.

Hirsch, A. R. (1992). Nostalgia: A neuropsychiatric understanding. *Advances in Consumer Research, 19*, 390−395.

Honing, H. (2011). *Musical Cognition. A Science of Listening*. New Brunswick, NJ: Transaction Publishers.

Honing, H., & Ladinig, O. (2008). The potential of the internet for music perception research: A comment on lab-based versus web-based studies. *Empirical Musicology Review, 3*(1), 4−7.

Honing H., & Reips, U. (2008). Web-based versus lab-based studies: A response to Kendall (2008). *Empirical Musicology Review, 3*(2), 73−77.

Hulen, P. (2006). A musical scale in simple ratios of the harmonic series converted to cents of twelve-tone equal temperament for digital synthesis. *WSEAS Transactions on Computers, 8*(5), 1713−1719.

Huron, D. (1994). Interval-class content in equally-tempered pitch-class sets: Common scales exhibit optimum tonal consonance. *Music Perception, 11,* 289−305.

Huron, D. (2006). *Sweet anticipation: Music and the Psychology of Expectation*. Cambridge, MA: MIT Press.

Huron, D. (2008). A comparison of average pitch height and interval size in major- and minor-key themes: Evidence consistent with affect-related pitch prosody. *Empirical Musicology Review, 3*, 59−63.

Huron, D., & Davis, M. J. (2012). The harmonic minor scale provides an optimum way of reducing average melodic interval size consistent with sad affect cues. *Empirical Music Review, 7*, 103−117.

Huron, D., & Margulis, E. (2010). Musical expectancy and thrills. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 575−604). Oxford, UK: Oxford University Press.

Hutchinson, W., & Knopoff, L. (1978). The acoustical component of Western consonance. *Interface, 7*, 1−29.

Hutchinson, W., & Knopoff, L. (1979). The significance of the acoustic component of consonance in Western triads. *Journal of Musicological Research*, 5−22.

Ilie, G., & Thompson, W. F. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception, 23*, 319−329.

Internet 1. (n.d.). Retrieved from http://www.psyk.uu.se/digitalAssets/31/31192_Scale_15-item_ENG.pdf

Internet 2. (n.d.). Retrieved from http://marcs-survey.uws.edu.au/OMSI/omsi.php

Itoh, K., Suwazono, S., & Nakada, T. (2010). Central auditory processing of noncontextual consonance in music: an evoked potential study. *Journal of the Acoustical Society of America, 128*, 3781−3787.

Janata, P. J., Tomic, S. T., & Rakowski, S. K. (2007). Characterization of music-evoked autobiographical memories. *Memory, 15*, 845−860.

Jensen, T. (1999). *Timbre models of musical sounds*, Rapport 99/7. Copenhagen, Denmark: University of Copenhagen.

Johnson-Laird, P. N., Kang, O. E., & Leong, Y. C. (2012). On musical dissonance. *Music Perception, 30*(1), 19−35.

Juslin, P. (2011). Music and emotion: seven questions, seven answers. In I. Deliège & J. Davidson (Eds.), *Music and the mind: essays in honour of John Sloboda* (pp. 113−135). New York: Oxford University Press.

Juslin, P. (2013). What does music express? Basic emotions and beyond. *Frontiers in Emotion Science, 4 (article 596)*, 1−14.

Juslin, P., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code? *Psychological Bulletin, 129*, 770−814.

Juslin, P., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research, 33*(3), 217−238.

Juslin, P., & Scherer, K. (2005). Vocal expression of affect. In J. Harrigan, R. Rosenthal & K. Scherer (Eds.), *The New Handbook of Methods in Nonverbal Behavior Research* (pp. 65−135). New York and Oxford, UK: Oxford University Press.

Juslin, P., & Sloboda, J. (2010a). *Handbook of music and emotion: Theory, research, and applications*. Oxford, UK: Oxford University Press.

Juslin, P., & Sloboda, J. (2010b). Introduction. Aims, organization, and terminology. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 3−12). Oxford, UK: Oxford University Press.

Juslin, P., & Timmers, R. (2010). Expression and communication of emotion in music performance. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 453−489). Oxford, UK: Oxford University Press.

Juslin, P., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences, 31*, 559−621.

Juslin, P., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). An experience sampling study of emotional reactions to music: Listener, music, and situation. *Emotion, 8*, 668−683.

Juslin, P., Liljestrom, S., Västfjäll, D., & Lundqvist, L. (2010). How does music evoke emotions? Exploring the underlying mechanisms. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 605−642). Oxford, UK: Oxford University Press.

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory. Part 1: Consonance of dyads. *Journal of the Acoustical Society of America, 45*, 1451−1459.

Kaminska, Z. & Woolf, J. (2000). Melodic line and emotion: Cooke's theory revisited. *Psychology of Music, 28*, 133−153.

Kastner, M., & Crowder, R. (1990). Perception of the major/minor distinction: IV. Emotional connotations in young children. *Music Perception, 8*, 189−202.

Kilmer, A. (1998). The musical instruments from Ur and Ancient Mesopotamia. *Expedition, 40*(2), 12−18.

Kilmer, A., & Civil, M. (1986). Old Babylonian musical instructions relating to hymnody. *Journal of Cuneiform Studies, 38*, 94−98.

Koelsch, S., & Friederici, A. D. (2003). Toward the neural basis of processing structure in music: Comparative results of different neurophysiological

investigation methods. *Annals of the New York Academy of Sciences, 999*, 15−28.

Koelsch, S., Fritz, T., Cramon, V., Muller, K., & Friederici, A. D. (2006). Investigating emotion with music: an fMRI study. *Human Brain Mapping, 27*, 239−250.

Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition*. 3−7 August, 2004. Evanston, IL: Northwestern University.

Krimphoff, J., McAdams, S., & Winsberg, S. (1994). Caractérisation du timbre des sons complexes. II: Analyses acoustiques et quantification psychophysique (Timbre characterization of complex sounds. II: Acoustical analyses and psychophysical quantifications). *Journal de Physique, 4*(C5), 625−628.

Krumhansl, C. (1990). *Cognitive Foundations of Musical Pitch*. New York: Oxford University Press.

Krumhansl, C. (2002). Music: A link between cognition and emotion. *Current Directions in Psychological Science, 11*(2), 45−50.

Kuusi, T. (2009). Discrimination and evaluation of trichords. *Music Theory Online, 15*(5). Retrieved from http://www.mtosmt.org/issues/mto.09.15.5/mto.09.15.5.kuusi.html

Kuusi, T. (2010). Comparing non-tonal tetrachords and pentachords: Both abstract properties and chordal characteristics guide evaluations. *Journal of New Music Research, 39*, 215−225.

Kuusi, T. (2011). Kuulijoiden adjektiiviassosiaatiot soinnuista – sointujen laatuominaisuuksia, kuulijoiden kokemuksia vai musiikkiin liittyviä emootioita? (Listener evaluations of chords – connections between chordal characteristics, adjective associations and emotions?) *Musiikki-lehti, 2*, 63−93.

Kuusi, T. (2015). Musical training and musical ability: Effects on chord discrimination. *Psychology of Music, 43*(2), 291−301.

Lartillot, O., & Toiviainen, P. (2007). MIR in Matlab (II): A toolbox for musical feature extraction from audio. In *Proceedings of the 8th International Conference on Music Information Retrieval*, Vienna, Austria, 23–27 September (pp. 237−244). Österreichische Computer Gesellschaft.

Lartillot, O., Toiviainen, P., & Eerola, T. (2008). A Matlab toolbox for music information retrieval. In C. Preisach, H. Burkhardt, L. Schmidt-Thieme & R. Decker (Eds.), *Data analysis, machine learning and applications* (pp. 261−268). Berlin, Germany: Springer.

Lazarus, R. (1991). *Emotion and Adaptation*. Oxford, UK: Oxford University Press.

Lerdahl, F. (1988). Tonal pitch space. *Music Perception, 5*, 315−345.

Lippius, J. (1612/1977). *Synopsis of New Music*. Edited and translated by Benito V. Rivera. Colorado Springs: Colorado College Music Press.

Lundin, R. (1947). Toward a cultural theory of consonance. *The Journal of Psychology, 23*, 45−49.

Maher, T. (1976). "Need for resolution" ratings for harmonic musical intervals: A comparison between Indians and Canadians. *Journal of Cross Cultural Psychology, 7*, 259−276.

Maher, T. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *American Journal of Psychology, 93*, 309−327.

Maher, T., & Jairazbhoy, N. (1975). Need for resolution of musical intervals, part I: Static context. *Sangeet Natak, 36*, 5−20.

Malm, W. (1996). *Music Cultures of the Pacific, The Near East, and Asia*. Upper Saddle River, NJ: Prentice Hall.

Malmberg, C. F. (1918). The perception of consonance and dissonance. *Psychological Monographs, 25*(2), 93−133.

Marin, M. M., Thompson, W. F., Gingras, B., & Stewart, L. (2015). Affective evaluation of simultaneous tone combinations in congenital amusia. *Neuropsychologia, 78*, 207−220.

Masataka, N. (2006). Preference for consonance over dissonance by hearing newborns of deaf parents and of hearing parents. *Developmental Science, 9*, 46−50.

McDermott, J., Lehr, A., & Oxenham, A. (2010). Individual differences reveal the basis of consonance. *Current Biology, 20*, 1035−1041.

McDermott, J., Schultz, A., Undurraga, E., & Godoy, R. (2016). Indifference to dissonance in native Amazonians reveals cultural variation in music perception. *Nature, 535*(7613), 547−550.

McLachlan, N., Marco, D., Light, M., & Wilson, S. (2013). Consonance and pitch. *Journal of Experimental Psychology; General, 142*, 1142−1158.

Mellinger, D., Mont-Reynaud, B. (1996). Scene analysis. In H. Hawkins, T. McMullin, A. Popper & R. Fay (Eds.), *Auditory computation* (pp. 271−331). New York: Springer Verlag.

Meyer, L. B. (1956). *Emotion and Meaning in Music*. Chicago, IL: The University of Chicago Press.

Minati, L., Rosazza, C., D'Incerti, L., Pietrocini, E., Valentini, L., Scaioli, V., & Bruzzone, M. G. (2009). Functional MRI/Event-related potential study of sensory consonance and dissonance in musicians and nonmusicians. *NeuroReport, 20*, 87−92.

Mitchell, D. (2002). Eternity or nothingness? Mahler's fifth symphony. In D. Mitchell & A. Nicholson (Eds.), *The Mahler companion* (pp. 236−325). New York: Oxford University Press.

Motte-Haber, H. (1971). Konsonanz und Dissonanz als Kriterien der Beschreibung von Akkorden (Consonance and dissonance as criteria for describing chords). *Jahrbuch der Staatlichen Instituts für Musikforschung Preußischer Kulturbesitz für 1970*, 101−127.

Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing, 10*(2), 113−131.

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical sophistication using expert ratings* (Doctoral dissertation). Ohio State University.

Omigie, D. (2015). Basic, specific, mechanistic? Conceptualizing musical emotions in the brain. *Journal of Comparative Neurology, 524*(8), 1676−1686.

Pallesen, K., Brattico, E., Bailey, C., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2005). Emotion processing of major, minor, and dissonant chords: A functional magnetic resonance imaging study. *Annals of the New York Academy of Sciences, 1060*, 450−453.

Parncutt, R. (1989). *Harmony: A Psychoacoustical Approach*. Berlin, Germany: Springer-Verlag.

Parncutt, R. (2004). *Psychoacoustics and music perception*. Submitted chapter to Bruhn, Kopiez, & Lehmann (2008): Musikpsychologie – das neue Handbuch.

Parncutt, R. (2012a). Major-minor tonality, Schenkerian prolongation, and emotion: A commentary on Huron and Davis (2012). *Empirical Music Review, 7*, 118−137.

Parncutt, R. (2012b). Psychoacoustics and cognition for musicians. In A. Brown (Ed.), *Sound musicianship: Understanding the crafts of music* (pp. 76−87). Cambridge: Cambridge Scholars Publishing.

Parncutt, R. (2014a). Roughness and beats. In W. F. Thompson (Ed.), *Music in the social and behavioral sciences: An encyclopedia* (pp. 970−972). Los Angeles, CA: Sage.

Parncutt, R. (2014b). The emotional connotations of major versus minor tonality: One or more origins? *Musicae Scientiae, 18*(3), 324−353.

Parncutt, R., & Hair, G. (2011). Consonance and dissonance in theory and psychology: Disentangling dissonant dichotomies. *Journal of Interdisciplinary Music Studies, 5*, 119−166.

Peretz, I. (2010). Towards a neurobiology of musical emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 99−126). Oxford, UK: Oxford University Press.

Persichetti, V. (1978). *Twentieth-Century Harmony: Creative Aspects and Practice*. London: Faber and Faber.

Philip, J. (1966). *Pythagoras and the Pythagoreans*. Toronto: University of Toronto Press.

Pierce, J. (1999). The nature of musical sound. In D. Deutsch (Ed.), *The psychology of music, 2nd edition* (pp. 11−23). San Diego, CA: Academic Press.

Plack, C. (2010). Musical consonance: the importance of harmonicity. *Current Biology, 20*, R476−R478.

Plantinga, J., & Trehub, S. E. (2014). Revisiting the innate preference for consonance. *Journal of Experimental Psychology: Human Perception and Performance, 40*, 40−49.

Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *Journal of the Acoustical Society of America, 38*, 548−560.

Rameau, J.-P. (1722/1971). *Treatise on Harmony*. Translated by Philip Gossett. New York: Dover Publications.

Randel, D. M. (2003). *The Harvard Dictionary of Music*. Cambridge, MA: Belknap Press of Harvard University Press.

Rentfrow, P. J., & Gosling, S. D. (2003). The do re mi's of everyday life: The structure and personality correlates of music preferences. *Journal of Personality and Social Psychology, 84*, 1236−1256.

Révész, G. (1954). *Introduction to the Psychology of Music*. Translated by G. I. C. De Courcy. Norman: University of Oklahoma Press.

Robbins, C., & Robbins, C. (1998). *Healing Heritage: Paul Nordoff Exploring the Tonal Language of Music*. Gilsum, NH: Barcelona Publishers.

Roberts, L. (1986). Consonance judgments of musical chords by musicians and untrained listeners. *Acustica, 62*, 163−171.

Russell, J. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*, 1161−1178.

Schenker, H. (1906). *Harmonielehre* [Harmony]. Stuttgart: J. G. Cotta.

Scherer, K. R. (1986). Vocal affect expression: A review and a model for future research. *Psychological Bulletin, 99*, 143−165.

Schimmack, U., & Grob, A. (2000). Dimensional models of core affect: A quantitative comparison by means of structural equation modeling. *European Journal of Personality, 14*, 325−345.

Schoenberg, A. (1922/1990). *Theory of Harmony*. Translated by Roy E. Carter. London: Faber and Faber.

Shapira Lots, I., & Stone, L. (2008). Perception of musical consonance and dissonance: An outcome of neural synchronization. *Journal of The Royal Society Interface, 5*, 1429−1434.

Shiba, R., & Nemoto, I. (2004). Perception of consonance and dissonance of musical chords: a magnetoencephalographic study. In S. Lipscomb, R. Ashley, R. Gjerdingen & P. Webster (Eds.), *Proceedings of the 8th International Conference on Music Perception and Cognition (ICMPC8)* (p. 307). Evanston, IL: USA. Adelaide, Australia: Causal Productions.

Sloboda, J. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music, 19*, 110−120.

Sloboda, J., & Juslin, P. (2010). At the interface between the inner and outer world: Psychological perspectives. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 73−97). Oxford, UK: Oxford University Press.

Spencer, H. (1857). The origin and function of music. *Fraser's Magazine, 56*, 396−408.

Stumpf, K. (1890). *Tonpsychologie (Vol.2)* [Tone Psychology (Vol.2)]. Leipzig: Verlag S. Hirzel.

Stumpf, K. (1898). Konsonanz und Dissonanz (Consonance and dissonance). *Beiträge zur Akustik und Musikwissenschaft, 1*, 1−108.

Sugimoto, T., Kobayashi, H., Nobuyoshi, N., Kiriyama, Y., Takeshita, H., Nakamura, T., & Hashiya, K. (2010). Preference for consonant music over dissonant music by an infant chimpanzee. *Primates, 51*, 7−12.

Taruskin, R. (2005). *The Oxford History of Western Music: Vol 1, The Earliest Notations to the Sixteenth Century*. New York: Oxford University Press.

Tenney, J. (1988). *A History of 'Consonance' and 'Dissonance'*. New York: Excelsior Music Publishing Company.

Terhardt, E. (1974). On the perception of periodic sound fluctuations (roughness). *Acustica, 30,* 201−213.

Terhardt, E. (1984). The concept of musical consonance: A link between music and psychoacoustics. *Music Perception, 1*, 276−295.

Thompson, W., Schellenberg, E., & Husain, G. (2004). Decoding speech prosody: Do music lessons help? *Emotion, 4*(1), 46−64.

Toch, E. (1948). *The Shaping Forces in Music*. New York: Criterion Music Corporation.

Trainor, L., & Heinmiller, B. (1998). The development of evaluative responses to music: Infants prefer to listen to consonance over dissonance. *Infant Behavior and Development, 21*, 77−88.

Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological foundations for the theory of harmony in Western tonal music. *Annals of the New York Academy of Sciences, 930*, 92−116.

Vassilakis, P. (2001). *Perceptual and physical properties of amplitude fluctuation and their musical significance* (Unpublished doctoral dissertation). University of California, Los Angeles.

Watson, D., Clark, L., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scale. *Journal of Personality and Social Psychology, 54*, 1063−1070.

Webster, G. D., & Weir, C. G. (2005). Emotional responses to music: Interactive effects of mode, texture, and tempo. *Motivation and Emotion, 29*, 19−39.

Werman, D. S. (1977). Normal and pathological nostalgia. *Journal of the American Psychoanalytic Association, 25*, 387−398.

Wildschut, T., Sedikides, C., Arndt, J., & Routledge, C. (2006). Nostalgia: Content, triggers, functions. *Journal of Personality and Social Psychology, 91*, 975−993.

Virtala, P., Huotilainen, M., Partanen, E., Fellman, V., & Tervaniemi, M. (2013). Newborn infants' auditory system is sensitive to Western music chord categories. *Frontiers in Auditory Cognitive Neuroscience, 4*(492), 1−10.

Vuoskoski, J. K. (2012). *Emotions represented and induced by music: The role of individual differences* (Doctoral dissertation). University of Jyväskylä.

Zarlino, G. (1573/1966). *Le Istitutioni Harmoniche*. Farnborough: Gregg Press.

Zentner, M., & Eerola, T. (2010). Self-report measures and models of musical emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 187−221). Oxford, UK: Oxford University Press.

Zentner, M., & Kagan, J. (1998). Infants' perception of consonance and dissonance in music. *Infant Behavior & Development, 21*, 483−492.

Zentner, M., Grandjean, D., & Scherer, K. (2008). Emotions evoked by the sound of music: Characterization, classification, and measurement. *Emotion, 8*, 494−521.

Zwicker, E., & Fastl, H. (1990). *Psychoacoustics: Facts and Models*. Berlin, Germany: Springer-Verlag.

Zwicker E., & Zwicker, U. (1991). Audio engineering and psychoacoustics: Matching signals to the final receiver, the human auditory system. *Journal of the Audio Engineering Society 39*, 115−126.

ORIGINAL PAPERS

I

SINGLE CHORDS CONVEY DISTINCT EMOTIONAL QUALITIES TO BOTH NAÏVE AND EXPERT LISTENERS

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Single chords convey distinct emotional qualities to both naïve and expert listeners

Imre Lahdelma[1] and Tuomas Eerola[2]

Abstract

Previous research on music and emotions has been able to pinpoint many structural features conveying emotions. Empirical research on vertical harmony's emotional qualities, however, has been rare. The main studies in harmony and emotions usually concern the horizontal aspects of harmony, ignoring emotional qualities of chords as such.

An empirical experiment was conducted where participants (N = 269) evaluated pre-chosen chords on a 9-item scale of given emotional dimensions. 14 different chords (major, minor, diminished, augmented triads and dominant, major and minor seventh chords with inversions) were played with two distinct timbres (piano and strings).

The results suggest significant differences in emotion perception across chords. These were consistent with notions about musical conventions, while providing novel data on how seventh chords affect emotion perception. The inversions and timbre also contributed to the evaluations. Moreover, certain chords played on the strings scored moderately high on the dimension of 'nostalgia/longing,' which is usually held as a musical emotion rising only from extra-musical connotations and conditioning, not intrinsically from the structural features of the music. The role of background variables to the results was largely negligible, suggesting the capacity of vertical harmony to convey distinct emotional qualities to both naïve and expert listeners.

Keywords

chord, emotion perception, harmony, timbre, vertical harmony

Many studies have addressed the role of different musical factors in creating emotional meaning in music such as tempo, mode, articulation (e.g., Gabrielsson & Lindström, 2010; Gagnon & Peretz, 2003; Juslin & Sloboda, 2010a; Webster & Weir, 2005), but the role of vertical harmony has been rather neglected in such studies. According to Gabrielsson and

[1]University of Jyväskylä, Finland
[2]Durham University, UK

Corresponding author:
Imre Lahdelma, Department of Music, University of Jyväskylä, P.O. Box 35 (M), 40014, Jyväskylä, 40014, Finland.
Email: imre.d.lahdelma@student.jyu.fi

Lindström, 'research on harmony has focused on the effects of consonance and dissonance, while there is practically nothing on how different kinds of chords . . . may affect expression' (2010, p. 393). Composers from Jean-Philippe Rameau to Béla Bartók have attended to vertical harmony's emotional connotations, the former acknowledging the power of chords to 'excite different passions in us' (Rameau, 1722/1971, p. 154), the latter pondering on the relationship between the chord 'as a physical phenomenon and the emotion signified by it' (as cited in Frigyesi, 1998, p. 147). Music therapist and composer Paul Nordoff suggests that every chord 'has its emotional impact, each one carries its emotional quality . . .' (as cited in Robbins & Robbins, 1998, p. 199).

In regard to emotional qualities conveyed by harmony's vertical dimension, the emphasis has mainly been theoretical (e.g., Cooke, 1959; Meyer, 1956) without empirical support. There have been some empirical attempts to investigate the emotional qualities conveyed by vertical harmony, but such studies have either focussed on harmonic intervals (e.g., Costa, Bitti, & Bonfiglioli, 2000; Krantz, Merker, & Madison, 2004; Maher, 1980; Oelmann & Laeng, 2009) or on the major/minor triad distinction (e.g., Crowder, 1985; Heinlein, 1928; Kastner & Crowder, 1990). The perceived sonority of consonance/dissonance in (mostly) triad chords has also been studied empirically by, for example, Roberts (1986), Cook (1999), Pallesen et al. (2005) and Bidelman & Krishnan (2011). Kuusi (2009, 2011) also touches upon the issue of how listeners perceive single chords aesthetically, but focuses mainly on non-traditional (non-tonal) chords and adjectives defining chord qualities rather than on actual emotions conveyed by chords.

The precise definition of what emotions are in regard to music is notoriously problematic, 'even if there is agreement over their general characteristics and subcomponents' (Eerola, Ferrer, & Alluri, 2012, p. 50). When talking about the emotional qualities of single isolated chords, the phenomenon in question is most likely *emotion perception*. Juslin and Sloboda (2010b, p. 10) describe this term being 'used to refer to all instances where a listener perceives or recognizes emotions in music (e.g., 'a sad expression'), without necessarily feeling an emotion him- or herself.'

When using the term *vertical harmony*, we are referring to the perception of a *chord* – 'a simultaneity of three or more notes' (Parncutt, 1989, p. 2). Psychoacoustically, chords are perceived as single acoustic objects rather than as multiple tones (Bregman, 1990), echoing Gestalt psychology's notion that the whole is different from the sum of its parts (Schiffman, 2001). By distinguishing vertical harmony from *horizontal harmony* we make sure no confusion emerges – horizontal harmony refers to the successive coincidence of pitches (harmonic progressions). Horizontal harmony's emotional effects have been studied empirically by, for example, Sloboda (1991), Webster and Weir (2005), Grewe, Kopiez, and Altenmüller (2009) and Grewe, Nagel, Kopiez, and Altenmüller (2007). The current study offers new insight into horizontal harmony's emotional effects as well, since single chords can be regarded as the smallest components of harmony's horizontal dimension (Aldwell & Schachter, 1989).

The question of perceived consonance and dissonance has been the main paradigm to study the perception of single chords, and has also been linked to their emotional qualities. For example, Terhardt (1974) suggests that single isolated chords are evaluated on the basis of sensory consonance, while harmony is seen as a higher cognitive process.

The effect of different distances between intervals has also been evaluated in relation to emotional qualities conveyed by chords (e.g., Meyer, 1956), and harmony's horizontal dimension might also influence vertical harmony perception. Tramo and colleagues, for example (Tramo, Cariani, Delgutte, & Braida, 2001, p. 96), suggest that 'a listener's implicit (or explicit) knowledge about harmony in the horizontal dimension bears on harmony perception in the vertical dimension,' an idea also implied by Cooke's (1959) semantic approach to vertical harmony's emotional qualities in a tonal context. Cooke's (1959) semantic approach implies that

these tonal relations are working not only in horizontal harmony, but in its vertical equivalent as well.

Finally, conventions also influence the perception of chords. Meyer (1956) calls a simultaneous group of sounds which lead the listener to expect a more or less probable consequent event a 'sound term;' for example, the dominant seventh chord yields a strong expectation to hear the tonic chord, even when heard in isolation rather than in the context of a passage of music. In sum, chords have been implicated to convey 'different emotional characteristics' in past research but most of these studies regard chords within horizontal and tonal contexts. As such, tonal chords in isolation have not been subject to focussed empirical study.

In contemporary music research, both theory and empiricism play significant roles (Honing, 2011). The aim of the current experiment is to gather empirical data on how single chords convey emotional qualities to listeners. While some scholars have disputed single chords having expressive qualities or intrinsic properties (e.g., Davies, 2010; Hevner, 1936; Lundin, 1985), according to previous empirical research there is little doubt that even such abstract and reduced musical stimuli as single isolated chords do indeed convey emotional qualities. For example, Pallesen et al. (2005) have demonstrated that neural processing in emotion-related brain areas is activated even by single chords. The very nature of these emotions, however, has so far remained unclear and calls for elaborate empirical research.

Experiment

In the current experiment, we asked participants to rate single chords (triads and seventh chords with inversions, all played in isolation rather than incorporated into a passage of music) on a 9-item emotion scale, constructed on the basis of findings from previous studies on music and emotions. Even though the basic emotion categories (e.g., happiness, sadness) are probably the easiest to recognize and communicate in music (e.g., Juslin & Laukka, 2003; Peretz, 2010), we felt that focusing solely on these basic emotion categories would perhaps fail to reflect the more subtle variations of perceived emotions in single chords. Zentner, Grandjean, and Scherer (2008) suggest that musical emotions tend to occur in a blended manner: blended or mixed emotions can have features of both positive and negative qualities, for example the emotion of 'nostalgia.'

The first three bipolar dimensions of the 9-item scale were adopted from Schimmack and Grob (2000). Their three-dimensional model of affect attempts to capture the core affects using the three bipolar dimensions of *Valence* (intrinsic attractiveness or aversiveness), *Energy arousal*, and *Tension arousal*. The advantage of the dimensional approach is that it separates effectively blended or mixed emotions (Eerola & Vuoskoski, 2011). The other five unipolar dimensions were chosen on the basis of *The Geneva Emotional Music Scales* (*GEMS*) 'derived from confirmatory factor analyses of ratings of emotions evoked by various genres of music' (Zentner & Eerola, 2010, p. 206), and *The Uppsala 15-item Scale for Measuring Emotional Reactions to Music* (Internet 1, n.d.). The resulting 9-item emotion scale consisted of the dimensions of 1) *Valence*, 2) *Tension*, 3) *Energy*, 4) *Nostalgia/longing*, 5) *Melancholy/sadness*, 6) *Interest/expectancy*, 7) *Happiness/joy*, and 8) *Tenderness*. As an extra 'dimension,' we measured the participants' *liking/preference* for each chord.

We decided to include the mixed, 'complex' emotion of *nostalgia/longing* in the 9-item scale as according to Juslin and Laukka (2004, p. 225) nostalgia 'may be one of the more commonly felt emotions to music.' Moreover, Zentner et al. (2008) identify nostalgia in their Geneva Emotional Music Scale. The dimension of *interest/expectancy* was included because it is considered to be an important general feature in regard to music and emotions (Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008). Out of the five basic musical emotions (happiness, sadness,

tenderness, fear, anger), we decided to omit fear and anger, as fear has been considered an example of a musical emotion arising mainly from conditioning (Zentner & Eerola, 2010), while anger may have more to do with psychophysical cues present in the actual musical context (tempo, dynamics, phrasing) than with single isolated chords. To minimize the effect of different interpretations of the emotion scales between participants, we explained each emotion more elaborately in the instructions of the experiment to let the respondents know how we ourselves understood the given terms (see the Appendix).

Method

Participants

The participants for the study were recruited through the internet with the aim of attracting both musicians and non-musicians, and thus having a heterogeneous, large and international participant pool (for a review of the benefits of this strategy, see Honing & Ladinig, 2008; Honing & Reips, 2008). The experiment was advertised through social media (Facebook, LinkedIn) and on many emailing lists of different universities around the world. As an incentive, two €35 gift cards to Amazon.com were offered in a draw for all participants who provided their email addresses with their responses for this purpose. The total number of respondents was 289, out of which 281 were considered valid for further statistical analysis. Eight sets of answers were excluded based on reports of technical problems (some chords did not play because of server issues), and due to obvious misunderstandings of instructions in the musical sophistication questionnaire. Of the remaining 281 participants, 12 extreme outliers were removed (described in more detail in the Results), making the final number of participants 269.

In total, 29 different nationalities were represented in the final participant pool. The biggest nationality groups were Finland (47.2%), the USA (17.8%) and New Zealand (8.2%). The participants were aged 17–71 years (mean = 30.1, *SD* = 12.8, 56.1% females); 68% of the participants were between 17 and 29 years of age. In total, 72% of the participants reported having a university degree, making the participant pool highly educated on average. The participants' musical sophistication was measured with the *Ollen Musical Sophistication Index* (Ollen, 2006), a 10-item questionnaire yielding a score for every participants' musical sophistication between 0 and 999 (mean 424.5, *SD* = 326.3). The participants were divided into four musical sophistication groups according to their OMSI scores, the score of 500 being the threshold between a musician and a non-musician (see Marcs Auditory Laboratories, Internet 2, n.d.). Non-musicians were divided into lower (OMSI score < 250, $N = 116$) and higher (250 ≤ OMSI score < 500, $N = 54$) groups, respectively. The musicians were also divided into lower (500 ≤ OMSI score < 750, $N = 35$) and higher (OMSI score ≥ 750, $N = 64$) groups, respectively.

Stimuli

The chord material consisted of triads and seventh chords with inversions based on the root of C (middle C) without transpositions. The triad chords were those of C major (C), C minor (Cm), C diminished (C^o) and C augmented (C+). C major and C minor were played in their root positions and in their first and second inversions, respectively. Diminished (C^o) and augmented (C+) triads were played only in their root positions as the augmented triad is the same chord regardless of its inversion, and the diminished triad's inversions were not anticipated to offer unique contributions to the parent chord's emotional impact. The seventh chords were those of C dominant seventh (C7), C minor seventh (Cm7) and C major seventh (Cmaj7), all played in their

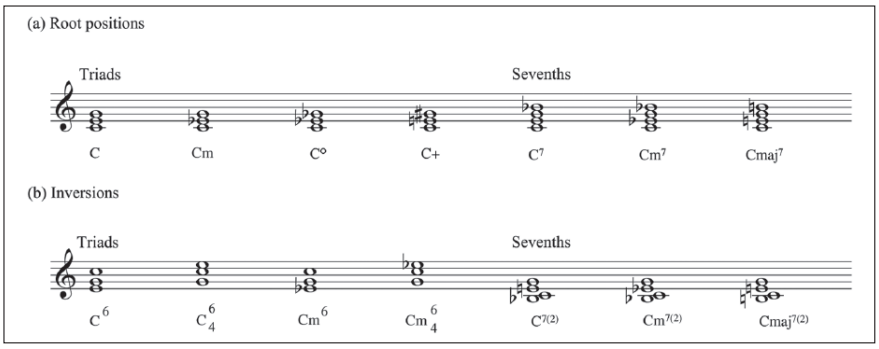

Figure 1. The chord stimuli.

root positions and in their 3rd inversions, respectively. The reason for choosing the 3rd inversion in addition to the root position was that in these two positions, the seventh note is either the lowest under the root (3rd inversion) or the uppermost above the triad. These two extreme positions were anticipated to yield the most notable differences in the actual emotion perception. The minor major seventh chord (Cmmaj7) was not included in the experiment to keep the total number of chords relatively low, and to avoid making the experiment too long for the participants. Thus, the stimuli were 14 chords in total (Figure 1) played with two different timbres (piano and strings), making the total sum of chords 28. All chords were exactly 4.0 seconds in duration, and played in equal temperament. All the chords were based on identical MIDI representations which were created as audio files using the following high-quality sample libraries; the piano chords were generated with Pro Tools HD 10, using a Virtual Instrument plug-in (*Ivory*) for piano sounds. The applied sound was *Bosendorfer Imperial 10* with some slight ambience reverb added to the chord samples to make them sound more natural. The string chords were generated with the *Vienna Symphonic Library* musical instrument samples using the *Chamber Strings* sound and were also treated with a touch of reverb. The attack, articulation and reverb values of the chords were kept as neutral as possible to keep the participants' attention exclusively on the emotion perception. The stimuli can be found online at https://www.jyu.fi/music/research/coe/materials/emotion/chords

Procedure

The Web-based chord evaluation application was programmed with JavaScript and was available exclusively in English. The application was made specifically for the purpose of the current experiment and was accessible online between 12 September 2012 and 15 October 2012. It was programmed to gather the participants' demographic background information (gender, nationality, age, education). The application made sure that every question was answered before letting the participant move on to the next page.

After gathering the demographic information, the affective mood of the participants was measured with the Positive and Negative Affect Schedule-measurement (PANAS; Watson, Clark, & Tellegen, 1988). The PANAS measurement is a tool used to measure the participants' positive and negative affects by using 5 positive and 5 negative adjectives. The participants were asked to rate each adjective on a scale from 1 to 5 (1 = *very slightly or not at all*, 2 = *a little*,

Table 1. Correlations between the nine dimension variables.

		1	2	3	4	5	6	7	8	α
1	Valence									.83
2	Tension	.08								.76
3	Energy	.48**	.50**							.83
4	Nostalgia	.00	.11	.08						.89
5	Melancholy	−.25**	.09	−.09	.74**					.88
6	Interest	.32**	.33**	.46**	.31**	.18**				.87
7	Happiness	.56**	.02	.37**	.20**	−.02	.53**			.86
8	Tenderness	.22**	−.16**	.04	.48**	.34**	.34**	.51**		.90
9	Liking	.49**	−.02	.32**	.26**	.06	.51**	.52**	.44**	.92

**Correlation is significant at the 0.01 level (2-tailed).

3 = *moderately*, 4 = *quite a bit*, 5 = *extremely*). After taking the PANAS measurement, the participants were allowed to start the chord evaluation phase. The participants received the following instructions:

> Listen to each chord as many times as you like before evaluating it. What are the emotional connotations that the chords seem to convey? Rate each chord on the given psychological dimensions. If you are not sure about the meaning of a dimension, just drag your mouse on it and an explanation will show.

The participants were asked to rate each chord on the presented 9-item scale before proceeding to the next chord (see the Appendix). The first three bipolar dimensions were rated on a Likert scale ranging from 1 to 5. With 'valence,' the bipolar extremes were 1 = *negative*, 5 = *positive*. With 'tension,' the extremes were 1 = *relaxed*, 5 = *tense*, and with 'energy,' the extremes were 1 = *low*, 5 = *high*. The six unipolar dimensions were rated on a Likert scale ranging from 1 to 5 (1 = *very slightly or not at all*, 2 = *a little*, 3 = *moderately*, 4 = *quite a bit*, 5 = *extremely*). The participants were given the chance to listen each chord as many times as they preferred. The ordering of the chords was randomized for each participant. The random ordering may have yielded tonal relationships between some chords, but the participants were specifically instructed to listen to each chord as a separate entity.

Results

All extreme outliers (over ± 2.5 *SD*'s, 3 in total) in the dimension aggregations and PANAS measurements (over ± 3.0 *SD*'s on any single PANAS adjective, nine overall) were removed from the participant pool. This resulted in removal of 12 participants' responses, and made the final number of valid cases 269. For statistical analysis, nine different scales were constructed by aggregating all the 28 chord ratings of each participant on each of the nine dimensions. The rating scales' internal consistency was measured with Cronbach's alpha (range .76−.92; see Table 1 for details). It is noteworthy how such reduced stimuli as single isolated chords yielded such high internal consistency: the obtained Cronbach's alphas are comparable to previous empirical studies on music and emotions where complete musical excerpts were used as stimuli (Eerola & Vuoskoski, 2011; Zentner et al., 2008). Correlations between the nine variables were calculated (Table 1). The strongest correlations were found between the dimensions of *melancholy/sadness* and *nostalgia/longing* (.74), and between

Table 2. Two-way ANOVA for all dimensions.

	Chord		Timbre		Chord × Timbre	
	F	η_G^2	F	η_G^2	F	η_G^2
Valence	348.0***	.38	5.4	.00	8.3***	.01
Energy	22.6***	.03	0.10	.00	10.7***	.01
Tension	157.0***	.21	0.43	.00	12.9***	.01
Nostalgia	75.6***	.09	99.9***	.04	4.79**	.00
Melancholy	240***	.25	74.7***	.02	7.9***	.01
Interest	27.0***	.04	6.6	.00	2.3	.00
Happiness	419.0***	.41	29.1***	.01	14.6***	.01
Tenderness	89.0***	.11	57.9***	.02	4.48**	.00
Liking	24.9***	.03	13.8**	.00	2.2	.00

p <.05; ** p <.01; *** p <.001 (two-tailed); df = 6,1608 for Chord, df = 1,268 for Timbre, and df = 1,1608 for Chord × Timbre. All p values corrected for sphericity with Greenhouse-Geisser procedure and for multiple testing with Bonferroni adjustment.

happiness/joy and *valence* (.56). However, none of the dimensions demonstrated complete overlap with each other and most correlations were in line with past research using complete excerpts with a noteworthy exception of *valence* and *energy* (.48), which have not been correlated in past studies (Eerola & Vuoskoski, 2011).

Our subsequent analysis framework used repeated measures ANOVA. For each emotion dimension, we carried out two main analyses (firstly overall analysis of chord type and timbre, and then more precise analysis of chord qualities). These were followed by three analyses of background variables (nationality, gender, and musical sophistication). To guard against inflated family-wise error rates associated with multiple testing, we utilized Bonferroni corrections for the five subsequent analyses of each dimension. Moreover, any post-hoc analyses within the main analyses also employed Bonferroni corrections. Since the design in some of the cases was not balanced (there were different quantities of observations across chord inversions depending on the chord quality, e.g., triads and seventh chords), the Greenhouse-Geisser adjustment was also utilized to control for the violations in sphericity.

The effect of musical factors on the chord evaluations

To estimate whether the emotion ratings across the chords and timbre differed statistically, a two-way repeated-measures analysis of variance was carried out for each emotion dimension with the Chord Type and Timbre (Piano and Strings) as the two within-subject factors. Chord Type consisted of the seven main categories of chords in which the inversions were collapsed into the main types of chords. This analysis yielded robust main effects of Chord Type for all dimensions (see Table 2 and Figure 2) and significant main effects of timbre for several, albeit not all, emotion dimensions. In all cases, except for Liking, there was also a weak interaction between the factors. The summary of the analysis of variance (Table 2) reveals that for valence, happiness, and melancholy, the differences in emotion ratings across the Chord Types were strikingly large (i.e., effect sizes above .25). Interestingly, the timbre differences across the emotion dimensions were rather selective exhibiting the largest differences in *nostalgia/longing, melancholy/sadness, tenderness*, and *happiness/joy*. Next, we take a closer look at the separate factors across rated dimensions.

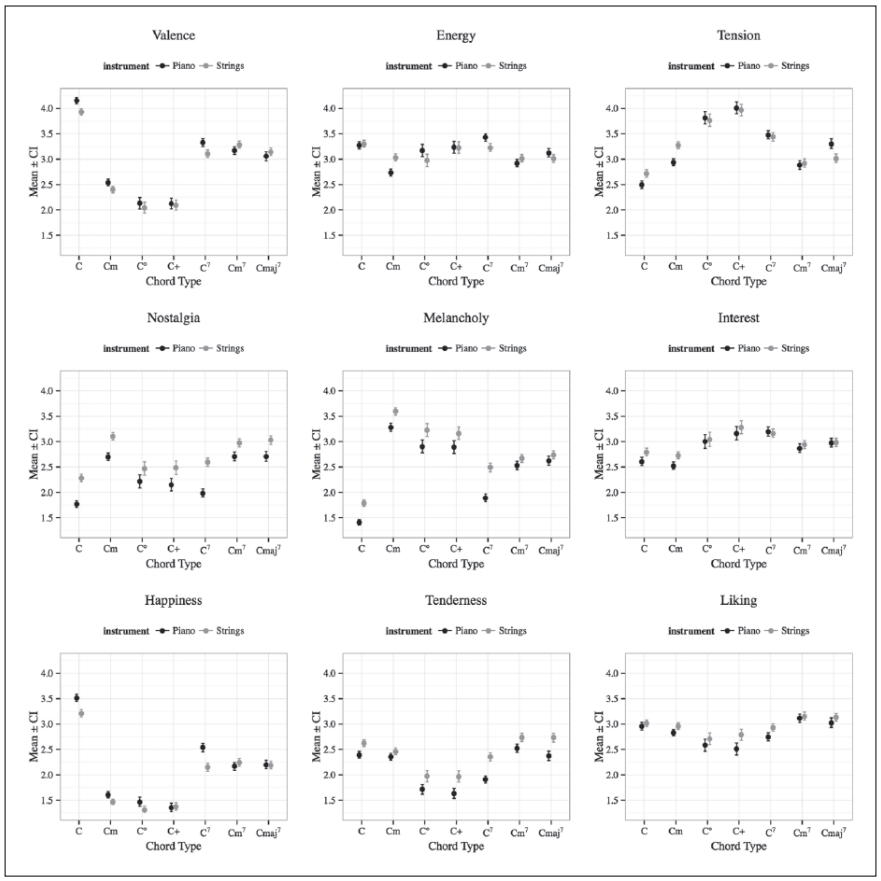

Figure 2. Mean ratings of the nine emotion dimensions across chord types and instrument.

Chord type. The main effects of the Chord Types across the emotion dimensions provide an interesting pattern of results. If we look at the effects of Chord Type (aggregated over timbre and disregarding those scales that displayed marginal effect sizes [η^2<.05]), the perceived *valence* was the highest for the major triad with a mean of 4.04 (*SD* = 0.61), and the lowest for the diminished triad with a mean of 2.09 (*SD* = 0.80). The latter was very close to the augmented triad's mean of 2.11 (*SD* = 0.76). To simplify the reporting of the large number of post-hoc comparisons, we report the Bonferroni adjusted values for $p < .05$ level for each dimension which enables the reader to assess the differences between the levels of the Chord Type. In *valence*, post-hoc tests separated major, minor, diminished/augmented, and seventh chords, but failed to separate diminished/augmented and seventh chords from each other. Perceived *tension* was highest for the augmented triad (*M* = 3.99, *SD* = 0.80), the second highest for the diminished triad (*M* = 3.79, *SD* = 0.78) and the third highest for the dominant seventh (*M* = 3.46, *SD*

= 0.61). The lowest mean rating of *tension* was for the major triad (M = 2.61, SD = 0.79); the differences between the triads were all statistically significant. Perceived *nostalgia/longing* was highest for the minor triad (M = 2.90, SD = 0.77), statistically on the same level as the major seventh (M = 2.89, SD = 0.82) and the minor seventh (M = 2.84, SD = 0.77). The lowest mean rating on the dimension of *nostalgia/longing* was for the major triad with 2.03 (SD = 0.73). The perceived *melancholy/sadness* was highest for the minor triad with a mean of 3.44 (SD = 0.77), followed by the diminished triad (M = 3.07, SD = 0.98) and the augmented triad (M = 3.03, SD = 1.00). The lowest *melancholy/sadness* mean rating was for the major triad with a mean of 1.60 (SD = 0.62). The perceived *happiness/joy* was highest for the major triad, with a mean rating of 3.36 (SD = 0.81) followed by the dominant seventh, considerably lower at M = 2.34 (SD = 0.80). The lowest *happiness/joy* mean rating was for the augmented triad (M = 1.37, SD = 0.53), all showing differences larger than the post-hoc cut-off values. The perceived *tenderness* was highest for the minor seventh (M = 2.63, SD = 0.82) followed by the major seventh (M = 2.52, SD = 0.84). The lowest mean rating of *tenderness* was for the augmented triad (M = 1.80, SD = 0.78).

Timbre. The most prominent differences of timbre in emotion dimension ratings were found in the dimensions of *nostalgia/longing* and *sadness/melancholy*, where the strings timbre had significantly higher mean ratings than the piano. Significant difference of timbre was observed in *nostalgia/longing,* $F(268) = 99.9$, $p < .005$, $\eta^2 = .04$, where the strings (M = 2.74, SD = 0.60) obtained higher ratings than piano (M = 2.33, SD = 0.68). On the dimension of *melancholy/sadness*, the difference was also clear: 2.76 (SD = 0.65) vs. 2.43 (SD = 0.55), $F(268) = 74.7$, $p < .001$, $\eta^2 = .02$. The strings also scored higher on the dimension of *tenderness*: 2.48 (SD = 0.66) vs. 2.23 (SD = .60), $F(268) = 57.9$, $p < .001$, $\eta^2 = .02$. Respectively, the piano timbre had significantly higher mean ratings on the dimension of *happiness/joy*: 2.29 (SD = 0.49) vs. 2.12 (SD = 0.48), $F(268) = 29.1$, $p < .01$, $\eta^2 = .01$. To summarize, timbre was indisputably affecting the emotional connotations of the chords in seven out of the nine emotion scales. *Energy* and *tension* were the only emotion scales which did not exhibit a statistically significant effect of timbre in the ANOVA.

Inversions. The role of inversions for emotion ratings was compared with separate repeated ANOVAs since the inversions were incomplete across the Chord Types (major and minor triads having two inversions, seventh chords having one, and augmented and diminished triads having no inversions at all). After discarding the data concerning augmented and diminished chords, a two-way ANOVA examined the Inversion (root or any inversion) and Chord Type (triad or seventh) for each emotion dimension, which resulted in significant main effects of Inversion for *valence, energy, tension, interest/expectancy* and *happiness/joy* (see Table 3). Moreover, all emotion dimensions exhibited significant interaction between Inversion and Chord Type, suggesting that the inversion made a particularly strong contribution to the ratings in major and minor triads. To clarify this relationship, we provide a visualization of the inversions for triads for selected dimensions (*valence, energy* and *tension*, see Figure 3). These three dimensions are the ones frequently featured in past emotion studies, but they also contain strong interactions between Inversions and Chord Types.

As we can see, with the major triad the tendency was that *valence, tension* and *energy* all exhibited a pattern of increasing ratings from root through first inversion to second inversion on both timbres (see Figure 3 for p values of contrasts between the inversions within the chords). For example, the major triad's valence mean ratings increased from the root position (M = 3.91, SD = 0.92), through the first inversion (M = 4.22, SD = 0.78) to the second inversion (M = 4.32, SD =

Table 3. Two-way ANOVA across inversion and chord quality for all dimensions.

	Inversion		Chord quality		Inversion × Chord quality	
	F	η_G^2	F	η_G^2	F	η_G^2
Valence	26.7***	.01	0.71	.00	63.3***	.02
Energy	93.3***	.03	15.3**	.01	303***	.11
Tension	30.2***	.01	97.2***	.10	117**	.05
Nostalgia	1.3	.00	28.2***	.02	15.2**	.00
Melancholy	3.8	.00	2.4	.00	27.4**	.01
Interest	32.4***	.01	84.5*	.08	60.0***	.02
Happiness	48.2***	.01	18.3***	.01	101***	.04
Tenderness	3.3	.00	0.8	.00	14.2**	.01
Liking	6.2	.00	6.1	.00	4.4	.00

* p <.05; ** p <.01; *** p <.001 (two-tailed); df = 1,268 for both inversion and chord quality. All p values corrected for multiple testing with Bonferroni adjustment.

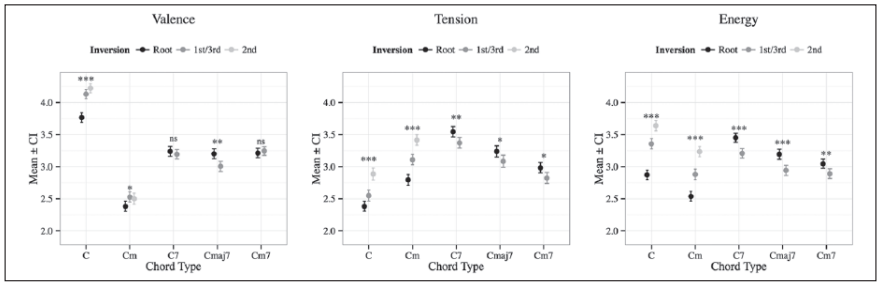

Figure 3. Mean ratings of the three emotion dimensions across Chord Types and Inversions (root, first and second for triads, and root and 3rd for seventh chords).

0.82). A similar pattern also occurred for *interest/expectancy* and *happiness/joy*. This tendency was the same with the minor triad, but the effect was much weaker as can be seen from the valence means: root position M = 2.41 (SD = 0.94), first inversion M = 2.59 (SD = 0.98) and second inversion M = 2.62 (SD = 1.1). Curiously, with both major and minor triads the *liking/preference* ratings also increased according to this same pattern. The possible explanations of the differences in mean ratings due to inversions will be elaborated on in the discussion section.

The effect of background factors on the chord evaluation

Demographic background. Independent t tests were used to investigate the differences in mean ratings according to different demographic background factors (gender, age, nationality and education). Of the different background factors, gender, nationality and musical sophistication affected the mean ratings of the chords the most. Education and age did not exhibit any significant differences across the emotion ratings. Females perceived significantly more *nostalgia/longing* (M = 2.63, SD = 0.54 vs. M = 2.41, SD = 0.57); $t(267) = -3.20$, p = .01 (Bonferroni

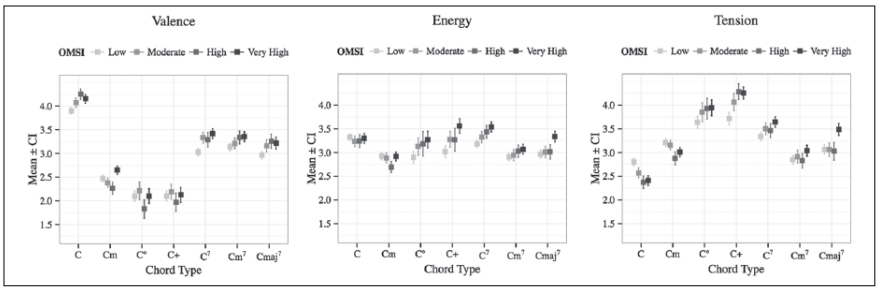

Figure 4. Mean ratings of the three emotion dimensions across chord types and musical sophistication.

adjusted), Cohen's $d = .39$, and more *melancholy/sadness* (2.68, $SD = 0.50$ vs. 2.48, $SD = 0.55$); $t(267) = -3.24$, $p = .005$, Cohen's $d = .40$, than males. The mean ratings of the two biggest nationality groups (US and Finland) were compared to the mean ratings of other nationalities. US citizens perceived less *nostalgia/longing* (2.35, $SD = 0.50$ vs. 2.57, $SD = 0.57$); $t(267) = 2.47$, $p = 0.07$, Cohen's $d = 0.41$, although the trend was not statistically significant and less *melancholy/sadness* (2.28, $SD = 0.44$ vs. 2.66, $SD = 0.53$); $t(267) = 4.70$, $p < .005$, Cohen's $d = 0.79$, than other nationalities. Respectively, Finnish citizens perceived more *melancholy/sadness* (2.70, $SD = 0.50$ vs. 2.50, $SD = 0.54$); $t = -3.20$, $p = .01$, Cohen's $d = 0.39$ than other nationalities.

Prevailing mood. The effect of prevailing mood on the chord evaluation was measured with bivariate correlations. The 10 PANAS adjectives were reduced into two scales: positive and negative mood. The positive scale consisted of the five positive adjectives ($\alpha = .80$), the negative scale of the five negative adjectives ($\alpha = .70$). The positive scale correlated most saliently with the dimensions of *energy,* $r(267) = .18$, $p = .003$, *interest/expectancy,* $r(267) = .18$, $p < .001$, and *liking/preference,* $r(267) = .17$, $p = .004$. The negative scale correlated most saliently with *tenderness,* $r = .17(267)$, $p = .007$.

Musical sophistication. A one-way ANOVA was conducted between the musical sophistication groups to compare the mean ratings of chords on the nine different dimensions. There were statistically significant differences between the four groups only on the dimensions of *interest/expectancy,* $F(3, 265) = 4.53$, $p = .02$ (Bonferroni adj.), $\eta^2 = .05$ and *liking/preference,* $F(3, 265) = 5.74$, $p = .005$ (Bonferroni adj.), $\eta^2 = .06$. Post hoc comparisons (Tukey) between the musical sophistication groups revealed that musicians (higher) perceived more *interest/expectancy,* $p = .01$, and gave higher mean ratings for *liking/preference,* $p < .005$.

On a broad level, the difference of ratings between the groups differing in musical sophistication was quite small, only concerning *interest/expectancy* and *liking/preference*, and not the main emotion rating scales. Also, the effect sizes revealed the relative insignificance of these differences. Still, participants with higher levels of musical sophistication evaluated the chords more consistently at the extremes of the scales, according to musical conventions (Figure 4). For example, as we can see, musicians rated the major seventh chord as having more tension and the major triad as having less tension when compared to the ratings of non-musicians. To elaborate on the differences on each dimension in the mean ratings of the seven different chord categories (major triad, minor triad, diminished triad, augmented triad, dominant seventh,

minor seventh, major seventh), a one-way ANOVA was conducted. Each chord category contained all the mean ratings for all the chord positions (both root positions and inversions) played with both timbres. The most significant differences in effect sizes were found on the dimensions of *tension* in the augmented triad chord, $F(3, 265) = 9.50$, $p < .005$ (Bonferroni adjusted), $\eta^2 = .10$, and *interest/expectancy* in the augmented triad, $F(3, 265) = 9.75$, $p < .005$, $\eta^2 = .10$, and the dominant seventh chord, $F(3, 265) = 13.34$, $p < .005$, $\eta^2 = .13$. A post hoc analysis (Tukey) revealed that musicians (higher) gave statistically higher ($p = .005$) mean ratings for these chords than non-musicians (lower).

Acoustic properties of the chords. As can be seen from the results obtained from our data, the difference in emotional characterizations of single chords is tangible. One can ask, where do such clear differences stem from? Although some assume these emotional characterizations to be culturally learned (e.g., Cazden, 1980; Lundin, 1947), others have posited that they are directly linked to psychoacoustic properties (e.g., Helmholtz, 1895/1980; Terhardt, 1974) whilst intermediate positions have also been proposed (Cook & Fujisawa, 2006; Crowder, 1984; Juslin & Scherer, 2005). Tramo et al. (2001) suggest that in isolated chords the consonance/dissonance perception appears at peripheral levels of the auditory system, suggesting that sensitivity to sensory consonance and dissonance develops very early in life (e.g., Trainor, Tsang, & Cheung, 2002; Zentner & Kagan, 1996). To explore whether the acoustic properties of the chords contribute to the ratings of chords in the present study, we extracted a set of core features implicated in past studies of timbre and emotions (Eerola et al., 2012), namely roughness, brightness, irregularity, spectral flux and log attack time from all stimuli using MIR toolbox (version 1.5, Lartillot & Toiviainen, 2007). The roughness estimation used the psychoacoustic model by Vassilakis (2001), brightness was calculated as the balance between high- and low-frequency spectral energy (cut-off set to 1000Hz), and irregularity quantified the variation of the successive peaks in the spectrum using Jensen's algorithm (1999). Spectral flux was computed by calculating the Euclidean distance between successive frames and, finally, the log attack time was simply estimated from the onset of shape (from the valley to peak time, see Krimphoff, McAdams, & Winsberg, 1994). For the first four measures, the analysis frame was 42ms in duration, with 50% frame overlap. Interestingly, the acoustic properties of the chords did not correlate with the majority of the dimensions. The only exceptions were nostalgia and tenderness, which exhibited significant correlations with brightness ($r = .46$ and $.42$), roughness ($r = .50$ and $.38$), flux ($r = .54$ and $.48$), and attack time ($r = .50$ and $.42$, for all $df = 26$, $p<.05$), respectively. Of course, here the range of variation of the features is narrow due to construction of the stimuli, and the number of stimuli for this kind of correlational approach is limited. Nevertheless, these analyses suggest an interpretation similar to that of Tramo et al. (2001) and Parncutt (1989): that for chords, the pure acoustic explanation may not adequately account for their emotional characteristics since the ratings of the stimuli were frequently not correlated with the acoustic properties of the stimuli. Thus, the whole indeed seems different from the sum of its parts.

Discussion

This study aimed to investigate how single chords convey emotional qualities to listeners. Participants rated single chords (triads and seventh chords with inversions played on two distinct timbres) on a nine-item emotion scale, the results demonstrating that single chords indeed convey distinct emotional qualities to both musicians and non-musicians.

All emotion dimensions exhibited significant interactions between Chord Type and Inversion, suggesting that the inversions affect chords' emotional qualities, especially with triad chords. According to Paul Nordoff, with respect to triads, 'the inversions arouse expectation, so that actually there is an element of tension in an inversion that does not exist in the chord in the root position. The inversions point, they lead. They have a direction' (as cited in Robbins & Robbins, 1998, p. 54). Our data suggests that this is indeed the case: with both major and minor triads, *tension, energy* and *interest/expectancy* all exhibited pattern of increase from root, through first inversion to second inversion with both piano and string timbres. However, this effect may also be due to the fact that the chords were simply played in a higher register in their first and second inversions than in their root positions, with the seventh chords' slightly higher values for the root positions than their third inversions also implying that the higher register yields more perceived *tension* and *energy* (for similar observations, see Costa et al., 2000; Ilie & Thompson, 2006). Still, with the major triad, there is an interesting analogy with the chord's second inversion's position and the harmonic series: the pitches that constitute the major triad's second inversion (G–C–E) are actually in the same order as the third, fourth and fifth partials of the harmonic series following the first and second partials (the root across two octaves). The major third's positive valence is usually seen emerging from its early presence in the harmonic series (e.g., Cooke 1959; Helmholtz, 1895/1980), though for example Ball challenges this view by taking notice of the fact that

> the overtones become rapidly weaker after the first one or two, and so it isn't clear that the major third will register strongly enough in most of the sounds we hear to be perceived as a 'special' interval in relation to a tonic note. (2010, p. 68)

Nonetheless, the positive valence of the major triad's second inversion is tangible, and the harmonic series might affect this connotation in addition to the higher register of the chord position. Also of interest is how the major triad's second inversion is actually the only position of the chord not containing the minor third.

According to our data there was a prominent difference in the emotion perception for the chords depending which timbre they were played with. The strings scored significantly higher on the dimensions of *nostalgia/longing, melancholy/sadness* and *tenderness*, while the piano scored higher on the dimension of *happiness/joy*, echoing the results obtained with emotion ratings of isolated instrument examples (Eerola et al., 2012). The strings' highly emotional quality may be due to effective emotional contagion. According to Juslin & Västfjäll (2008) the voice-like aspects of music (for example, the timbre of the violin) are very effective at expressing emotions to listeners, leading the listener to mimic the perceived emotion internally.

On the basis of our results, musicians and non-musicians perceived the chords' emotional qualities quite similarly on a broad level. Curiously, the effect of musical sophistication on single chord perception is not nearly as conspicuous as it is on, for example, the perception of tension in short chord sequences (Bigand, Parncutt, & Lerdahl, 1996) or on the perception of emotions conveyed by speech prosody (Thompson, Schellenberg, & Husain, 2004). Our results are thus in line with the findings of Pallesen et al. (2005) who point out that musicians and non-musicians do not differ in their neural responses to single musical chords. They also propose that musicians' ability to recognize and categorize chords in terms of conventional emotional connotations does not necessarily result in an effective enhanced emotional experience. Concerning differences related to the background variables, nationality exhibited relatively few and minor differences in emotions (*nostalgia/longing* and *melancholy/sadness*). These emotions are perhaps the most culturally loaded terms among the used emotion dimensions (Hepper et al., 2014).

According to Meyer (1956, p. 267), 'communicative behavior tends to become conventionalised for the sake of more efficient communication, so the musical communication of moods and sentiments tends to become standardized.' On the basis of our results, this effect is prominent with common triads: the affective connotation of, for example, the classic major/happy minor/sad distinction is indisputable. The major triad was regarded as 'happy/joyful' and the minor triad as 'melancholic/sad,' corroborating the findings of Crowder (1984, 1985), Kastner & Crowder (1990), Pallesen et al. (2005) and McDermott, Lehr, and Oxenham (2010).

More formalized explanations for the emotional connotations of the chords have also been offered. For instance, Meyer (1956, p. 164) surmises that the effect of different distances between intervals creates distinct emotional qualities. According to him, augmented and diminished triads produce ambiguity, which is felt as 'intense emotion, apprehension, and anxiety' because of the 'intervallic equidistance' of the chords, i.e., even spacing between the tones within the chord. In the present findings, equidistant triads (diminished and augmented) seem to be compatible with Meyer's view since they exhibited the highest ratings of *tension* and the lowest ratings for *valence, happiness, tenderness* and *liking*. Concerning the emotional effects of seventh chords, Cooke (1959) has linked the major seventh to connotations of nostalgia/longing. Although his notion is rooted in tonality (and therefore pertinent to horizontal harmony), the present findings support the notion even though the tonal context is largely absent: the major seventh was rated as the most nostalgic chord alongside the minor triad.

As the minor seventh and the major seventh were, all in all, the most preferred chords, it is interesting to observe these chords' relationship to the question of consonance/dissonance. While we did not, in the current experiment, measure perceived consonance/dissonance, previous research makes a clear distinction between the 'dissonant' seventh chords and the 'consonant' major and minor triads. For example Révész (1954, p. 80) proposes that '. . . from a musical aspect there is absolutely no justification for according the minor seventh the same degree of consonance as the major and minor triads.' Even though there is indisputable semantic overlap of *consonant* and *pleasant* (Tramo et al., 2001), more perceived consonance does not automatically result in more preference for single chords, a finding that calls for further research.

A possible drawback with the predetermined dimensions used in the experiment is that the given choices might have influenced the participants to respond along the provided categories, and that the interpretation of the terms provided might vary considerably across populations, though this drawback is common to all methodologies relying on verbal methods (Zentner & Eerola, 2010). In regard to the suitability of the given dimensions to actual chord evaluation, an interesting tendency is that the dimension of *happiness/joy* received surprisingly low mean ratings and was used mainly for the major triad. Also the dimension of *tenderness* received quite low mean ratings in aggregate, suggesting that this dimension is not very apposite with respect to vertical harmony perception. On the basis of the responses, 'positive valence' seems to describe the emotional quality conveyed by single chords more accurately than the dimension of *happiness/joy*.

A possible limitation to the current study was the lack of control due to the Web-based design. While with a Web-based approach, control of participants is definitely not as rigid as with a Lab-based approach, Goslin, Vazire, Srivastava, and John (2004) and Honing and Ladinig (2008) have pointed out many advantages in Web-based studies. These include, for instance, demographic diversity and the possibility of reaching a large number of intrinsically motivated respondents, positively influencing the ecological validity of the results by allowing respondents to take part in the experiment from their home – an arguably more natural environment than the classic laboratory setup. As the experiment was conducted exclusively in English, there is the possibility of different interpretations of the emotion dimensions among

the different nationalities. However, those who ended up taking the experiment arguably had a high level of English proficiency, as the instructions in the beginning of the test were in English. Each emotion dimension's meaning was also meticulously explained in the experiment.

In actual music, different chords can create different affects depending on musical context and subjectivity plays a significant role in music perception. However, on the basis of our data, this does not mean that there are no underlying similarities to be found in regard to emotion perception, even within a highly heterogeneous pool of respondents. Our results demonstrated that there are indeed clear similarities in emotion perception of single isolated chords among a vast number of individuals with diverse demographic backgrounds. Further studies should address the issue of isolating the effects that yield these underlying similarities, and further disentangle nuances in how vertical harmony conveys distinct emotional qualities to listeners – for example, the fascinating phenomenon of vertical harmony being able to convey the complex and mixed emotion of *nostalgia/longing*. Also, the significant differences found with just two different timbres suggest a need for more research on the effect of timbre on chord perception, as does the obvious effect of inversions. Finally, we suggest that brain/neurological studies could take into account the notable diversity of emotional qualities that even single chords are able to convey.

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References

Aldwell, E., & Schachter, C. (1989). *Harmony and voice leading*. New York, NY: Harcourt Brace Jovanovich.

Ball, P. (2010). *The Music Instinct: How music works and why we can't do without it*. Oxford, UK: Oxford University Press.

Bidelman, G., & Krishnan, A. (2011). Brainstem correlates of behavioral and compositional preferences of musical harmony. *Neuroreport*, *22*(5), 212–216.

Bigand, E., Parncutt, R., & Lerdahl, J. (1996). Perception of musical tension in short chord sequences: The influence of harmonic function, sensory dissonance, horizontal motion, and musical training. *Perception & Psychophysics*, *58*, 125–141.

Bregman, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound*. Cambridge, MA: MIT Press.

Cazden, N. (1980). The definition of consonance and dissonance. *International Review of the Aesthetics and Sociology of Music*, *11*(2), 123–168.

Cook, N. D. (1999). Explaining harmony: The roles of interval dissonance and chordal tension. *Annals of the New York Academy of Science*, *930*, 382–385.

Cook, N. D, & Fujisawa, T. X. (2006). The psychophysics of harmony perception: Harmony is a three tone phenomenon. *Empirical Musicology Review*, *1*(2), 106–126.

Cooke, D. (1959). *The Language of Music*. Oxford, UK: Oxford University Press.

Costa, M., Bitti, P., & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music*, *28*, 4–22.

Crowder, R. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology*, *4*, 3–10.

Crowder, R. (1985). Perception of the major/minor distinction: III. Hedonic, musical, and affective discriminations. *Bulletin of the Psychonomic Society*, *23*, 314–316.

Davies, S. (2010). Emotions Expressed and Aroused by Music: Philosophical Perspectives. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 15–43). Oxford, UK: Oxford University Press.

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and affect dimensions: Evidence from affect and similarity ratings and acoustic correlates of isolated instrument sounds. *Music Perception: An Interdisciplinary Journal*, *30*(1), 49–70.

Eerola, T., & Vuoskoski, J. K. (2011). A comparison of the discrete and dimensional models of emotion in music. *Psychology of Music*, *29*(1), 18–49.

Frigyesi, J. (1998). *Béla Bartók and Turn of the Century Budapest*. Berkeley: University of California Press.

Gabrielsson, A., & Lindström, E. (2010). The role of structure in the musical expression of emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 393–414). Oxford, UK: Oxford University Press.

Gagnon, L., & Peretz, I. (2003). Mode and tempo relative contributions to 'happy - sad' judgments in equitone melodies. *Cognition and Emotion*, *17*(1), 25–40.

Goslin, S. D., Vazire, S., Srivastava, S., & John, O. P. (2004). Should we trust web-based studies? A comparative analysis of six preconceptions about internet questionnaires. *American Psychologist*, *59*(2), 93–104.

Grewe, O., Kopiez, R., & Altenmüller, E. (2009). Chills as an indicator of individual emotional peaks. *Annals of the New York Academy of Sciences*, *1169*, 351–354.

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007). Listening to music as a recreative process: Physiological, psychological, and psychoacoustical correlates of chills and strong emotions. *Music Perception*, *24*(3), 297–314.

Heinlein, C. P. (1928). The affective characteristics of the major and minor modes in music. *Journal of Comparative Psychology*, *8*(2), 101–142.

Helmholtz, H. (1980). *On the sensations of tone as a physiological basis for the theory of music*. Translated by A. Ellis. New York, NY: Dover. (Original work published 1895)

Hepper, E. G., Wildschut, T., Sedikides, C., Ritchie, T., Yung, Y.-F., Hansen, N., . . .Zhou, X. (2014). Pancultural nostalgia: Prototypical conceptions across cultures. *Emotion*, *14*(4), 733–747.

Hevner, K. (1936). Experimental studies of the elements of expression in music. *American Journal of Psychology*, *48*, 246–68.

Honing, H. (2011). *Musical Cognition*. A Science of Listening. New Brunswick, NJ: Transaction Publishers.

Honing, H., & Ladinig, O. (2008). The potential of the internet for music perception research: A comment on lab-based versus web-based studies. *Empirical Musicology Review*, *3*(1), 4–7.

Honing, H., & Reips, U.-D. (2008). Web-based versus lab-based studies: A response to Kendall (2008). *Empirical Musicology Review*, *3*(2), 73–77.

Ilie, G., & Thompson, W. F. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception*, *23*, 319–329.

Internet 1. (n.d.). Retrieved from http://www.psyk.uu.se/digitalAssets/31/31192_Scale_15-item_ENG.pdf

Internet 2. (n.d.). Retrieved from http://marcs-survey.uws.edu.au/OMSI/omsi.php

Jensen, T. (1999). *Timbre Models of Musical Sounds*, Rapport 99/7. Copenhagen, Denmark: University of Copenhagen.

Juslin, P., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code? *Psychological Bulletin*, *129*, 770–814.

Juslin, P., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research*, *33*(3), 217–238.

Juslin, P., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). An experience sampling study of emotional reactions to music: Listener, music, and situation. *Emotion*, *8*, 668–683.

Juslin, P., & Scherer, K. (2005). *Vocal expression of affect*. In J. Harrigan, R. Rosenthal & K. Scherer (Eds.), *The New Handbook of Methods in Nonverbal Behavior Research* (pp. 65–135). New York and Oxford: Oxford University Press.

Juslin, P., & Sloboda, J. (2010a). *Handbook of music and emotion: Theory, research, and applications*. Oxford, UK: Oxford University Press.

Juslin, P., & Sloboda, J. (2010b). Introduction. Aims, organization, and terminology. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 3–12). Oxford, UK: Oxford University Press.

Juslin, P., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences*, *31*, 559–621.

Kastner, M., & Crowder, R. (1990). Perception of the major/minor distinction: IV. Emotional connotations in young children. *Music Perception*, *8*, 189–202.

Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition*. 3–7 August, 2004. Evanston, IL: North Western University.

Krimphoff, J., McAdams, S., & Winsberg, S. (1994). Caractérisation du timbre des sons complexes. II: Analyses acoustiques et quantification psychophysique (Characterization of the timbre of complex sounds. II Acoustic analyses and psychophysical quantification). *Journal de Physique*, *4*(C5), 625–628.

Kuusi, T. (2009). Discrimination and evaluation of trichords. *Music Theory Online*, *15*(5). Retrieved from http://www.mtosmt.org/issues/mto.09.15.5/mto.09.15.5.kuusi.html

Kuusi, T. (2011). Kuulijoiden adjektiiviassosiaatiot soinnuista – sointujen laatuominaisuuksia, kuulijoiden kokemuksia vai musiikkiin liittyviä emootioita? (Listener evaluations of chords – connections between chordal characteristics, adjective associations and emotions?) *Musiikki-lehti*, *2*, 63–93.

Lartillot, O., & Toiviainen, P. (2007). MIR in Matlab (II): A toolbox for musical feature extraction from audio. In Proceedings of the 8th International Conference on Music Information Retrieval, Vienna, Austria, 23–27 September, 2007 (pp. 237–244). Österreichische Computer Gesellschaft.

Lundin, R. (1947). Toward a cultural theory of consonance. *Journal of Psychology*, *23*, 45–49.

Lundin, R. (1985). *An objective psychology of music*. Malabar, FL: Krieger.

Maher, T. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *American Journal of Psychology*, *93*, 309–327.

McDermott, J., Lehr, A., & Oxenham, A. (2010). Individual differences reveal the basis of consonance. *Current Biology*, *20*, 1035–1041.

Meyer, L. B. (1956). *Emotion and meaning in music*. Chicago, IL: The University of Chicago Press.

Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing*, *10*(2), 113–131.

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical sophistication using expert ratings* (Doctoral dissertation, Ohio State University). Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=osu1161705351

Pallesen, K., Brattico, E., Bailey, C., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2005). Emotion processing of major, minor, and dissonant chords: A functional magnetic resonance imaging study. *Annals of the New York Academy of Sciences*, *1060*, 450–453.

Parncutt, R. (1989). *Harmony: A psychoacoustical approach*. Berlin, Germany: Springer-Verlag.

Peretz, I. (2010). Towards a neurobiology of musical emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 99–126). Oxford, UK: Oxford University Press.

Rameau, J.-P. (1971). *Treatise on Harmony* (P. Gossett, Trans.). New York, NY: Dover Publications. (Original work published 1722)

Révész, G. (1954). *Introduction to the Psychology of Music* (G. I. C. De Courcy, Trans.). Norman: University of Oklahoma Press.

Robbins, C., & Robbins, C. (1998). *Healing heritage: Paul Nordoff exploring the tonal language of music*. Gilsum, NH: Barcelona Publishers.

Roberts, L. (1986). Consonance judgments of musical chords by musicians and untrained listeners. *Acustica*, *62*, 163–171.

Schiffman, H. R. (2001). *Sensation and perception: An integrated approach*. New York, NY: Wiley.
Schimmack, U., & Grob, A. (2000). Dimensional models of core affect: A quantitative comparison by means of structural equation modeling. *European Journal of Personality*, *14*, 325–345.
Sloboda, J. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music*, *19*, 110–120.
Terhardt, E. (1974). On the perception of periodic sound fluctuations (roughness). *Acustica*, *30*, 201–213.
Thompson, W., Schellenberg, E., & Husain, G. (2004). Decoding speech prosody: Do music lessons help? *Emotion*, *4*(1), 46–64.
Trainor, L., Tsang, C., & Cheung, V. (2002). Preference for sensory consonance in 2- and 4-month old infants. *Music Perception*, *20*, 187–194.
Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological foundations for the theory of harmony in western tonal music. *Annals of the New York Academy of Sciences, 930*, 92–116.
Vassilakis, P. N. (2001). *Perceptual and physical properties of amplitude fluctuation and their musical significance* (Unpublished doctoral dissertation). University of California, Los Angeles.
Watson, D., Clark, L., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scale. *Journal of Personality and Social Psychology*, *54*, 1063–1070.
Webster, G. D., & Weir, C. G. (2005). Emotional responses to music: Interactive effects of mode, texture, and tempo. *Motivation and Emotion*, *29*, 19–39.
Zentner, M., & Eerola, T. (2010). Self-report measures and models of musical emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 187–221). Oxford, UK: Oxford University Press.
Zentner, M., Grandjean, D., & Scherer, K. (2008). Emotions evoked by the sound of music: Characterization, classification, and measurement. *Emotion*, *8*, 494–521.
Zentner, M., & Kagan, J. (1996). Perception of music by infants. *Nature*, *383*, 29. Retrieved from http://www.zentnerlab.com/sites/default/files/15.pdf

Appendix: Elaborate explanations of each dimension on the 9-item scale

Bipolar dimensions

1. **Valence.** Is the chord conveying positive or negative feelings?
2. **Tension.** How tense do you think the chord is? Is it calm and relaxed or tense and agitated?
3. **Energy.** Do you think the chord is strong and energetic or weak and feeble?

Unipolar dimensions

4. **Nostalgia/longing.** Is the chord conveying feelings of nostalgia, wistfulness, or longing?
5. **Melancholy/sadness.** How much melancholy or sadness does the chord express?
6. **Interest/expectancy.** Is the chord sounding resolutive and definitive or is it conveying feelings of interest and expectancy?
7. **Happiness/joy.** How much happiness or joy does the chord express?
8. **Tenderness.** Is the chord sounding tender and affectionate?
9. **Liking/preference.** How much did you like the chord? Note that this is a purely subjective question: for example, you may have liked the chord no matter how sad or agitated it was.

II

THEORETICAL PROPOSALS ON HOW VERTICAL HARMONY MAY CONVEY NOSTALGIA AND LONGING IN MUSIC

by

Imre Lahdelma & Tuomas Eerola, 2015

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Theoretical Proposals on How Vertical Harmony May Convey Nostalgia and Longing in Music

IMRE LAHDELMA[1]
Department of Music, University of Jyväskylä, Finland

TUOMAS EEROLA
Department of Music, Durham University, UK

ABSTRACT: Music is often associated with the emotions of nostalgia and longing. According to previous survey studies, both nostalgia and longing are among the most common emotions evoked by music (Juslin, 2011). Despite nostalgia's significance as a musical emotion, research on the specific properties of music that might contribute to this particular emotion has been scarce. A recent empirical experiment by Lahdelma and Eerola (2014) sought to explore whether single chords could be effective at conveying musical emotions to listeners, which spanned complex emotions such as nostalgia/longing. According to the results, single chords such as the minor triad, the minor seventh and especially the major seventh communicated the emotion of nostalgia effectively. The aim of the current paper is to raise several possible explanations that might account for the ability of single chords to convey the emotion of nostalgia. In these explanations we consider cultural, music-theoretical and psychoacoustic issues, as well as their possible interactions. The three proposed candidate explanations are (1) *learning*, (2) *intrinsic emotional connotations arising from tonal relations*, and (3) *clashing conventions arising from concurrent yet separate affective associations, stemming from certain triad and interval combinations*. Finally, we propose experimental designs for future research to empirically test these explanations.

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KEYWORDS: *chord, vertical harmony, emotion, nostalgia, longing*

NOSTALGIA is a common emotion (Boym, 2001), described as a universal experience that transcends age groups and is present across the lifespan (Sedikides, Wildschut, & Baden, 2004). According to Wildschut, Sedikides, and Routledge (2008), the term nostalgia "derives from the Greek words nostos (return) and algos (pain)" (p. 20), literally meaning "the suffering evoked by the desire to return to one's place of origin" (p. 20). The New Oxford Dictionary of English (1998) defines nostalgia as "a sentimental longing or wistful affection for the past" (p. 1266), underlining the longing quality inherent in the emotion. According to Batcho (2007), "most theorists agree that the distinctive emotional character of nostalgia is bittersweet - a mix of sadness and wistful joy" (p. 362). Sedikides, Wildschut, Arndt, and Routledge (2008) propose that "nostalgia is triggered by dysphoric states such as negative mood and loneliness" (p. 304), but that it also generates positive affect. Nostalgia's positive effects have also been reported by, for example, Juhl and Routledge (2013) and Cheung et al. (2013).

These positive effects could be one reason why music is often called for to induce nostalgia, as music is a common source of nostalgia (e.g., Barrett et al., 2010; Zentner, Grandjean, & Scherer, 2008), and it often serves a nostalgic function in everyday life (Juslin, Harmat, & Eerola, 2013). Juslin (2011) proposes that on the basis of previous survey studies both nostalgia and longing are among the most common emotions evoked by music, and nostalgia's prominence among music-induced feelings has also been pointed out by, for example, Zentner and Eerola (2010). In a recent study by Taruffi and Koelsch (2014), nostalgia was indicated as the most frequent emotion evoked by sad music among a large and heterogeneous pool of participants. Interestingly, the prevalence of nostalgia in music is not only limited to *felt* emotional experiences, since it is common also as a *perceived* emotion in music (Juslin & Laukka, 2004).

The bittersweet component of nostalgia is present in its equivalent musical emotion. Zentner et al. (2008) suggest that musical emotions have a tendency to occur in a blended manner, and that these blended or mixed emotions can have features of both positive and negative qualities - nostalgia being a good example of an emotion encompassing a variety of closely related terms, including wistfulness and longing. For this reason, it is not surprising that many scholars have labelled this emotion with a dual label such as nostalgia/longing (e.g., Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008), and the two terms are being used more or less interchangeably in emotion questionnaires and subsequent factor structures derived from them (e.g., Zentner et al., 2008). Moreover, in music literature (e.g., Cooke, 1959; Mitchell, 2002) the terms "nostalgia" and "longing" are often also used interchangeably. To simplify the terminology, we will label this complex and blended emotion as *nostalgia* to encompass the most common variants, such as nostalgia/longing and wistfulness. We will return to the terminology question in the discussion section.

Despite nostalgia's significance as a musical emotion, research on the specific properties of music that contribute to this particular emotion has been scarce. Previous literature (Barrett et al., 2010; Janata, Tomic, & Rakowski, 2007; Wildschut, Sedikides, Arndt, & Routledge, 2006) suggests that the source of music-evoked nostalgic experience is in the idiosyncratic associations that people have formed between certain music and events in their past. Juslin and Västfjäll (2008) describe the term *episodic memory* as referring "to a process whereby an emotion is induced in a listener because the music evokes a memory of a particular event in the listener's life" (p. 567). While the case of idiosyncratic associations as a source of musical nostalgia may well explain the case of music-evoked, *felt* nostalgia, it does not take into account the possibility that music by itself could be able to *convey* and express nostalgia. Survey results have suggested that music is able to express nostalgia (e.g., Juslin & Laukka, 2004), although this does not rule out that memories would be the underlying cause. However, the empirical evidence that hints at the ability of unfamiliar music to convey nostalgia is scarce. A recent result from a cross-cultural comparison implies that listeners are able to recognize longing in improvised performances across cultures (Laukka, Eerola, Thingujam, Yamasaki, & Beller, 2013).

When we look at the musicological descriptions of pieces, music scholars often resort to the terms of nostalgia or longing. For example, Cooke (1959) mentions Frederick Delius depicting "obsessive nostalgia" (p. 76) in his music, Freeman (1992) describes Richard Wagner's music as the "language of longing", and Tagg (1993) uses the term nostalgia to depict musical moods. While some attempts have been made to depict certain musical structures conveying nostalgia (e.g., Key, 1995; Malin, 2006), this claim has remained contentious. A recent empirical experiment by Lahdelma and Eerola (2014) sought to explore whether single, isolated chords could be effective at conveying musical emotions to listeners, which spanned complex, mixed emotions such as nostalgia. Intriguingly, the results suggest that particular chords consistently convey nostalgia to listeners. In other words, the results imply that nostalgia could be considered as an inherent feature in music, and that vertical harmony might play a role in conveying this particular emotion. This is not only surprising in terms of inherent or learnt associations with music, but the brevity and the lack of musical context of the actual stimuli rule out musically complex explanations: in music, emotions are often seen as requiring time to unfold (e.g., Meyer, 1956). However, Schubert (2010) notes that "this is not mandatory to its definition, since an emotion can be detected in a static image or object such as a photograph" (p. 223). Also, studies by, for example, Bigand, Vieillard, Madurell, Marozeau, and Dacquet (2005), Eerola, Alluri, and Ferrer (2012), and Filipic, Tillmann, and Bigand (2010), suggest that extremely brief (< 1 s, or even < 250 ms) musical excerpts have the ability to communicate clear emotional signals. Even though it is widely held in music theory that single chords have musical significance only in relation to other chords (e.g., Hindemith, 1942), it is worth noting that even single chords in isolation are able to elicit brain responses that can be broadly discriminated in terms of emotions (e.g., Bakker & Martin, 2015; Pallesen et al., 2005).

The aim of the current study is to discuss *how* musical structures, particularly vertical harmony, could convey the complex, mixed emotion of nostalgia, the focus being on the *perception* of nostalgia as opposed to the *induction* of this particular emotion, and the framework being exclusively Western music. In this paper, we focus on chords since this is the only musical feature that has been linked with nostalgia in an empirical setting so far. We will also demonstrate the connection with concrete musical examples, drawn from the musicological literature.

CHORDS CONVEYING NOSTALGIA

In the recent study by Lahdelma and Eerola (2014), an empirical experiment was carried out where participants (*N* = 269) evaluated pre-selected chords on a 9-item scale of given (closed set of terms) emotional dimensions spanning both *basic* (e.g., *happiness* and *sadness*) as well as *mixed* emotions (e.g., *nostalgia/longing*). The emotion terms the experimenters selected were based on previous empirical research (e.g., Juslin et al., 2008; Zentner et al., 2008). Fourteen different chords (major, minor, diminished, and augmented triads and dominant, major and minor seventh chords with inversions) were played with two distinct timbres (piano and strings). The triad chords were those of C major (C), C minor (Cm), C diminished (C^o) and C augmented (C+). The seventh chords were those of C dominant seventh (C7), C minor seventh (Cm7) and C major seventh (Cmaj7), all played in their root positions and third inversions respectively. The results indicated that the minor triad, the minor seventh, and especially the major seventh chords were quite effective at conveying the complex emotional quality of nostalgia. Of the single chords, the minor triad's root position and the major seventh's third inversion scored highest on nostalgia. When played in the string timbre, the modal nostalgia rating of both the minor triad and the major seventh chord was 4 ("Quite a bit") on the 5-point Likert scale, in each chord position. That is, a typical listener perceived "quite a bit" of nostalgia in these particular chords, with the major seventh chord's third inversion conveying the emotion of nostalgia more effectively than its root position. Intriguingly, the major seventh chord's third inversion's mean rating was highest on the dimension of nostalgia of all the given dimensions when played on the strings, implying that this particular chord conveys nostalgia *par excellence*. While the experimenter-selected, closed set of dimensions may have guided the participants' evaluations to some extent, this drawback is common to all methodologies that rely on verbal methods (Zentner & Eerola, 2010). The strength of the original research protocol by Lahdelma and Eerola (2014) lies in the fact that the emotional dimensions that were utilized have been used in a large variety of past studies of emotional expression in music (e.g., Juslin & Laukka, 2004; Juslin et al., 2008). Moreover, with the original experiment's Likert scale there was always the possibility to rate a chord very low (the lowest position on the Likert scale was "*very slightly or not at all*") if it absolutely did not seem to fit a certain dimension-- a possibility the participants also clearly used if we take, for example, the "happiness" of the augmented triad.

As for *nostalgia/longing*, this dimension was quite exclusively used for the chords of the minor triad, the minor seventh and especially the major seventh, making it an intriguing and tangible case to investigate further. As the aim of their study was to explore whether single chords are able to convey distinct emotions, Lahdelma and Eerola (2014) did not pursue any theoretical explanations of their observations, despite the plain need for a theoretical rationale to account for complex emotions such as nostalgia/longing.

EXPLANATIONS FOR NOSTALGIA CONVEYED BY CHORDS

As a way of describing how single chords might convey the complex emotion of nostalgia, we consider cultural and music-theoretical explanations, as well as their possible interactions. In addition to these explanations, we outline a probable physical mapping that underlies the proposed explanations. Our candidate explanations are (1) *learning*, (2) *intrinsic emotional connotations arising from tonal relations*, and (3) *clashing conventions*. We will describe these next in detail.

Premise: Mapping Between Physical Properties and Affect States

Connections between the emotional expressiveness of physical sounds and underlying physiological states have been posited at least since the work of Spencer (1857), implying that different emotions actually cause physiological changes that alter vocal expression. This *physiological state explanation* (Scherer, 1986) accounts for emotions expressed in speech, which in turn bears on musically communicated emotions as well. Juslin and Laukka (2003) have shown that there are strong parallels between vocal expression and musical expression of basic emotions (e.g., happiness and sadness). Most of these connections relate to amplitude, tempo/speech rate, and timbre, but there are also links to be found between intervals and emotional states. For instance, according to Bowling, Gill, Choi, Prinz, and Purves (2010), the spectra of major intervals are more similar to spectra found in excited speech, whereas the spectra of particular minor intervals are more similar to the spectra of subdued speech. Also, Curtis and Bharucha (2010) propose that

the minor third occurs in the pitch contour of speech conveying sadness, as well as in music. Similarly, Huron (2008) has shown that small melodic intervals are more prevalent in sad than happy music, and demonstrated that this feature is directly related to the possible interval sizes available in scales (Huron & Davis, 2012). In general, connections between certain intervals (both vertical and horizontal) and emotional expression have been found in several empirical studies (e.g., Costa, Bitti, & Bonfiglioli, 2000; Cousineau, McDermott, & Peretz, 2012; Krantz, Merker, & Madison, 2004; Maher, 1980; Oelmann & Laeng, 2009), showing typically that the minor and the major second, and the minor and the major seventh are the most displeasing intervals, possessing the most negative *valence* (intrinsic attractiveness vs. aversiveness), with the major seventh also correlating with sadness ratings (e.g., Krantz et al., 2004).

The underlying reason why these particular intervals seem to be effective at conveying negative valence may be due to the amount of dissonance they contain (cf. Hutchinson & Knopoff, 1979; Kameoka & Kuriyagawa, 1969; Malmberg, 1918). Zentner and Kagan (1996) propose that the preferential bias for consonance could be innate, basing this view on their findings that even infants are biologically prepared to treat consonance as more pleasant than dissonance. This aversion to dissonance has a biological substrate. As Peretz (2010) puts it:

> Sensory dissonance can be created by two simultaneous tones one or two semitones apart. This combination creates beating at the level of the basilar membrane in the inner ear. The overlap in vibration patterns compromises the resolution of pitches of different frequency on the basilar membrane, leading to the perception of roughness. (p. 108)

However, McDermott et al. (2010) curiously attribute *harmonicity* as a more important factor in aversion to dissonance than *roughness*, with harmonicity meaning "how closely the spectral frequencies of a sound correspond to a harmonic series" (Parncutt, 1989, p. 172). For example, a major triad has high harmonicity as it is "more similar to the harmonic series as it exists among the audible partials of everyday harmonic complex tones such as voiced speech sounds" (Parncutt, 2012, p. 130). Moreover, as Johnson-Laird, Kang, and Leong (2012) point out, roughness in itself fails to predict the relative dissonance of, for example, common triad chords. It has been proposed that dissonance is in fact based on a *combination* of roughness, harmonicity and familiarity (Parncutt, 2012). These affective parallels between certain intervals and broad affects are likely to have an impact on the emotional perception of single chords too, as we will later demonstrate.

1) Learning

Learning seems to play an important role in the perception of emotions conveyed by vertical harmonies. Peretz (2010) suggests that "among adults, there is robust evidence that emotional responses are modulated by experience" (p. 103) and that "the unconscious affective influence of prior exposure to music may account for a vast array of phenomena" (p. 104). These phenomena include, for instance, the emotional distinction between the major and minor mode. These, in turn, are probably shaped by the underlying physical and physiological states mentioned in the previous section. Previous research indicates that tempo is mastered earlier than mode to judge the emotional tone conveyed by music (Dalla Bella, Peretz, Rousseau, & Gosselin, 2001). This suggests that the major-happy/minor-sad association is indeed learned, and that the major/minor triads can hence be seen in a Peircean sense as "indices" of happiness/joy and melancholy/sadness – at least in Western music. The origin of the major-happy/minor-sad association dates back to probably the 14th century and is still disputed (see for example Crowder, 1984; Parncutt, 2012, 2014). One recent study interestingly suggests that newborn infants' auditory systems are actually sensitive to Western music chord categories (Virtala, Huotilainen, Partanen, Fellman, & Tervaniemi, 2013). However, Parncutt (2012) points out that the major-happy/minor-sad association may be absent in historical or non-Western traditions that are not based on triadic harmony, but also suggests that the basis of the major/minor emotional distinction is not necessarily only in arbitrary associations. Similar suggestions have been made by, for example, Crowder (1984). Parncutt (2012, 2014) sees that the major mode is perceived as a standard form as opposed to the minor mode because music in major keys is more common in Western music. According to Parncutt, this is due to the major triad's closer similarity to the harmonic series and that the major triad is in this sense more consonant than the minor triad - a view suggested also by, for example, Helmholtz (1895/1980), Schenker (1906), and Schoenberg (1922/1990). Whatever the origin of the major/minor emotion convention might be, according to previous empirical

research (e.g., Lahdelma & Eerola, 2014; McDermott et al., 2010; Pallesen et al., 2005), the major triad is indisputably an effective index of happiness/joy, while the minor triad is an index of melancholy/sadness in Western culture, even though isolated major/minor triads' perception can, of course, also be affected by pitch height, loudness and timbre (Parncutt, 2012).

Contemplating the issue from a historical point of view, Tagg and Clarida (2003) suggest that

> the nineteenth-century Central European tonal system put minor modes de facto into the cultural position of archaisms. Ousted by the then 'more modern' major key, minor could acquire general connotations of oldness and the past and…lead associations…into nostalgia, quietude and sadness. (p. 313)

As for the effective mediation of these connotations, Tagg and Clarida point out that early film music grounded its semantic practices on European classical and romantic music. According to Cohen (2010) "films provide a major source for transmission of a culture's musical conventions" (p. 899). The emotional connotations that Tagg and Clarida attribute to the minor mode seem also to be present in the isolated minor triad chord as well (Lahdelma & Eerola, 2014).

However, cultural conventions effectively mediated by film music is not the only possible explanation as to how the minor triad is able to convey nostalgia, in addition to melancholy and sadness. Juslin et al. (2013) propose that as a music-evoked emotion, nostalgia can also be a by-product of sadness. Also, Wildschut et al. (2006) and Sedikides et al. (2008) suggest that sadness and negative mood is often a trigger of nostalgia. A recent study by Taruffi and Koelsch (2014) suggests that nostalgia is actually the most frequent emotion evoked by sad music. This could be surmised to be an effect of *episodic memory*, in the sense that the melancholic and sad stimuli trigger episodic memories and hence nostalgia. Juslin et al. (2013), for example, explain unfamiliar music's ability to arouse nostalgia in listeners with this particular mechanism. However, according to the empirical data of Lahdelma and Eerola (2014), the nostalgic minor seventh and major seventh chords scored relatively high on the dimension of *valence*, and the minor seventh chord in turn scored quite low on the dimension of *melancholy/sadness*. Also, this trigger could actually be any aspect of music, and pinning it down to particular chords is a tall order. Another crucial counterargument to this explanation is how in the above-mentioned data the augmented and the diminished chords conveyed *melancholy/sadness* effectively but conveyed *nostalgia/longing* rather ineffectively. These results imply that the mechanism of *episodic memory* by itself does not offer a comprehensive explanation of how single chords are able to convey nostalgia.

In sum, learning seems to account for the broad connotations of major-minor triads (happy and sad), but whether this goes further to encompass more complex emotions such as nostalgia is uncertain.

It could be argued that musical conventions utilize certain chords (e.g., major sevenths) in conveying nostalgia, longing and wistfulness in film music (e.g., Ennio Morricone's *Canzone della Nostalgia* [*Song of Nostalgia*] from the film *And Agnes Chose to Die* [1976] and Gustav Mahler's distinctively longing music used in, for instance, Luchino Visconti's *Death in Venice* [1971]), as well as in both classical and popular music. There are quite clear-cut examples to be found in musicological literature to illustrate the use of major seventh chords with specific regard to the expression of nostalgia and longing. According to Fleming and Veinus (1958), the major seventh chord in the final duet (*O terra addio)* from the opera *Aida* "...creates an almost unbearable tension that perfectly expresses the infinite longing of the doomed lovers on the brink of eternity" (p. 67). Curiously, Cooke (1959) also notes that in this very same closing duet the major seventh chord denotes a "violent longing for joy" (p 75). Cooke (1959) further discusses the major seventh chord and suggests that Delius "...found it most useful, added to the major triad, *pianissimo*, unresolved, to express his obsessive nostalgia (the opening chord of *On hearing the First Cuckoo in Spring*)" (p. 76), and that Sibelius "found it an admirable note to add to the tonic triad, *fortissimo*" at the end of his Seventh Symphony to convey a mood of intense "aspiration" (p. 76). Leonard Bernstein's (1976) analysis of Mahler's Fifth Symphony's *Adagietto* in his classic fourth Harvard lecture is also of interest here. When discussing the piece's "affective ambiguity," Bernstein (1976) specifically mentions the appoggiatura "E" in the melody being an "unresolved tug-at-the-heart" (p. 199) in the context of the F major chord. It is noteworthy how, in many sources, this "affective ambiguity" with regard to the Mahler Symphony and its *Adagietto* is interpreted as particularly "nostalgic" in nature. In the BBC Proms (2011) foreword with regard to the Fifth Symphony this connection is clear: "Written whilst he was recuperating from a sudden life-threatening illness, it is full of nostalgia" (BBC, 2011). Also, in the Mahler Companion (2002), edited by Donald Mitchell and Andrew Nicholson, this association is conspicuous and

rather remarkable: "...Visconti used the Adagietto in his film of Mann's Death in Venice (1971) as sonorous symbol of Aschenbach's nostalgia, frustrated passion, and hopeless longing..." (p. 310). With regard to pop music this linkage is also clear; for example, Everett (2008) discusses the major seventh chord sounding "nostalgic" and "wistful" (p. 200), while drawing concrete examples from songs like *Old Friends* by Simon and Garfunkel, and *Old Cape Cod* by Patti Page.

2) Intrinsic Emotional Meaning Built Into Tonality

Learning this connotation through extensive exposure to it in various musical styles and contexts is, however, only one possible explanation to account for nostalgia and longing being conveyed by the major seventh chord. In addition to the theory of *learning*, we contemplate the possibility of nostalgic emotional meaning arising from what Juslin (2013) calls *intrinsic coding*. Juslin (2013) explains *intrinsic coding* to involve internal syntactic relationships within the music itself. He also points out that intrinsic sources of musical expression in music have rarely been investigated, but that they are unlikely to express specific emotions by themselves. This explanation could theoretically account for the major seventh chord's ability to convey nostalgia, stemming from the tension of pitch relationships among tones that is present in tonality. Cooke (1959) explains the nostalgic or longing effect of the major seventh chord by proposing that its

> tension in relation to the triad is a semitonal one upwards the tonic, so that when it is exposed in relation to the major triad, the 'longing for pleasure' it evokes is so violent as to be almost painful. It is, moreover, a longing for pleasure in a context of finality, aiming to the tonic…(p. 76)

Previous empirical experiments have offered Cooke's semantic views only limited support (Kaminska & Woolf, 2000), or no corroboration at all (Gabriel, 1978). However, none of these experiments tested Cooke's views on the emotional effects of vertical harmony per se. Like Cooke, Huron (2006) also takes notice of the leading tone's distinctive *quale*, attributing it a "strong sense of precariousness or instability mixed with some urgency and accompanied by feelings of yearning or aspiring upward" (p. 144). As Huron (2006) suggests: "the feelings that precede highly expected events are quite distinctive" (p. 306). The leading tone's resolution upwards to the tonic is a highly expected outcome in Western harmony - according to an intriguing anecdote (see Kelly, 2001), composer Maurice Ravel had actually been eliminated from the Prix de Rome scholarship for ending a piece with a chord containing the major seventh.

Cooke's semantic theory (1959) implies that chords do not create emotional meaning solely by perceived consonance/dissonance, as is suggested by Terhardt's (1974) view that listeners evaluate single, isolated chords on the basis of sensory consonance and (horizontal) harmony through a higher cognitive process. Also, Huron (2006) proposes that "the ability of listeners to imagine a single tone as serving different tonal functions indicates that scale degrees are *cognitive* rather than *perceptual* phenomena" (p. 143), adding that scale degree is "how minds interpret physically sounding tones, not how tones are in the world" (p. 143). Cooke's line of thinking coincides also with the view of Tramo, Cariani, Delgutte, and Braida (2001), who suggest that "a listener's implicit (or explicit) knowledge about harmony in the horizontal dimension bears on harmony perception in the vertical dimension" (p. 96), suggesting that the perception of vertical and horizontal harmony are not necessarily that far apart. Krumhansl (1990) proposes that "a tonal context designates one particular tone as most central" and that "the other tones all have functions specified with respect to this tone" (p. 18). Tillman, Bharucha, and Bigand (2000) suggest that adults with little or no musical training also possess this implicit knowledge. Although Cooke's notion is clearly rooted in tonality and therefore pertinent to horizontal harmony (Cooke actually proposes that the longing effect of the major seventh is present when added specifically to the *tonic* triad), the findings of Lahdelma and Eerola (2014) suggest this effect is present in the single, isolated major seventh chord as well, without a tonal or musical context: the major seventh was rated as the most nostalgic chord alongside the minor triad in their data. According to Parncutt (2011), in major/minor tonality a chord must normally progress to its dominant and back before establishing a proper tonality. Thus, a single isolated chord most likely cannot function as a tonic, or to be precise, in this case the major seventh chord's triad "base" cannot function as a "tonic" to the seventh tone *within* the chord.

The "iconic" (in the Peircean sense) yearning stemming from tonal relations (*intrinsic coding*) in single chords is problematic for a number of other reasons, too. First, Juslin (2013) proposes that *intrinsic coding* may require a relatively long timespan (structures alternating in tension and release in a broader musical context) to be effective. Hence, a stimulus as short as a single chord would not count as the most probable candidate for being able to convey emotion by *intrinsic coding*, unless the chord's emotional meaning is actually rather effectively acquired from exposure to tonality (in this case the emotion perception of the major seventh chord would actually be a mixture of the explanations of *learning* and *intrinsic emotional connotations arising from tonal relations*, a possibility discussed further in the discussion section).

Second, if the additional tones would indeed create "iconic" tension in relation to the major triad as Cooke (1959) suggests, then why, one might ask, is the dominant seventh chord conveying this particular emotion quite ineffectively (cf. Lahdelma & Eerola, 2014)? After all, Cooke remarks that just as the major seventh is longing upwards to the tonic, the minor seventh is accordingly drawn downwards to the dominant. If the major seventh chord's nostalgia stems from "tension" and the leading tone's aspiration to the tonic, it is hardly corroborating his theory that in the dominant seventh's case, these same attributes do not seem to convey nostalgia in any effective way: it is noteworthy that the dominant seventh chord conveyed considerably less *nostalgia/longing* than the major seventh chord, but scored higher on the dimensions of *interest/expectancy* and *tension* (Lahdelma & Eerola, 2014). Cooke (1959) even suggests that the dominant seventh interval in relation to the major triad expresses "a gentle mournful feeling" (p. 74). In fact, according to the empirical results of Lahdelma and Eerola (2014), Cooke's view of the dominant seventh chord's "sad, empty sound" (p. 74) obtained no empirical support, since it scored relatively high on the dimension of *valence* but low on the dimension of *melancholy/sadness*. This also hints at the possibility that, accordingly, the minor seventh chord conveys nostalgia effectively because of its minor triad "base" rather than because of the minor seventh tone's longing to the sixth or to the dominant, as implied by Cooke's line of thinking.

Finally, the difference in the perceived amount of *nostalgia/longing* in the two inversions of the major seventh chord is also noteworthy (Lahdelma & Eerola, 2014). The higher amount of perceived *nostalgia/longing* in the third inversion including the interval of the minor second, as opposed to the root position including the interval of the major seventh, hints at the possibility that the presence of the most dissonant interval of the minor second (cf. Hutchinson & Knopoff, 1979; Kameoka & Kuriyagawa, 1969; Malmberg, 1918) creates more nostalgia in the chord than the presence of the slightly less dissonant major seventh. Both chord positions, however, clearly convey the emotion of nostalgia, and the difference in chord position might be stemming from a difference in register (in the root position the seventh tone is an octave higher than in the third inversion). As none of the presented explanations seem to comprehensively account for the major seventh chord's ability to convey nostalgia, we propose a new theory as the third explanation.

3) Clashing Conventions

According to Meyer (1956)

> States of calm contentment and gentle joy are taken to be the normal human emotional states and are hence associated with the more normative musical progressions, i.e., the diatonic melodies of the major mode and the regular progressions of major harmony. (p. 227)

These same attributes could well describe the isolated major triad as well, as it is highly effective at conveying happiness/joy on the basis of previous empirical research (e.g., Lahdelma & Eerola, 2014; McDermott et al., 2010; Pallesen et al., 2005). The major triad is also the most common chord in Western harmony (Huron, 2006). In light of the major triad's conventional role as the "norm" of positive valence (e.g., Meyer, 1956; Parncutt, 2012), one could consider how additional tones may alter its valence and emotional meaning, this time contemplated from another perspective than Cooke's (1959) suggestion of "iconic" meaning arising from tonal tension which attributes the leading tone a special "affective quale" (cf. Huron, 2006) in relation to the tonic. As mentioned in the premises section, the minor second and the major seventh intervals have been show empirically to score high on sadness and negative valence. Hence, these particular intervals could be seen as "obscuring" the positive valence of the triad, although not

altogether "obliterating" it. In other words, the "clashing" of two highly conventionalized indices (the major triad as an index of happiness/joy, and the dissonant intervals of the minor second and the major seventh as indices of negative valence and melancholy/sadness) could create new emotional meaning that is perceived as the complex emotion of nostalgia. In other words, both positive and negative emotions might be conveyed by the major seventh chord concurrently, creating "affective dissonance" which in turn is perceived as the bittersweet emotion of nostalgia. The proposed *clashing conventions* explanation is compatible with many analytical descriptions of nostalgia that combine happiness/joy and melancholy/sadness. On an aesthetic level, several definitions of nostalgia have intriguing parallels with this explanation. Batcho (2007), for example, suggests that conflict is inherent in the nostalgic experience, and that "theories that emphasize the bittersweet quality of nostalgic sentiment attribute the bitter side to the realization of the irretrievability of the past and the accompanying sense of irrecoverable loss" (p. 375). Nostalgia is also seen as a yearning for an idealized past (Hirsch, 1992). It is interesting to speculate about the major triad being the "idealized" item, the norm of positive valence which is altered or "obscured" by the sad and negative intervals of the minor second or the major seventh, which are also the sharpest dissonances (Hutchinson & Knopoff, 1979; Kameoka & Kuriyagawa, 1969; Malmberg, 1918). Also, Werman (1977) sees nostalgia as "wistful pleasure, a joy tinged with sadness" (p. 393). Again, the analogy of the major triad representing happiness/joy, while the minor second and its inversion--the major seventh--represent the tinge of melancholy/sadness, is striking. Interestingly, the major seventh chord is also the clashing of the major and minor triads (C-E-G, major; E-G-B, minor), and at this point it is not possible to rule out this inherent feature as a contributor in conveying the chord's nostalgic connotation in addition to the two sad and negative sounding intervals clashing with the major triad.

According to Juslin (2013), listeners' interpretations of emotions in music tend to gravitate towards basic categories and Juslin suggests that basic emotions (e.g., happiness, sadness) are at the core of human emotions. In the major seventh chord's case, one could argue that because these basic emotions are so strong, they might create more subtle nuances and convey mixed emotions when overlapping or being present concurrently. Juslin (2013) proposes that according to many emotion researchers, "mixed emotions" are founded on basic emotions that involve "blends" of emotions. Hunter, Schellenberg, and Schimmack (2010) suggest that there is "empirical evidence demonstrating that positive and negative affect (i.e., corresponding to opposite poles of the putative valence dimension) are activated simultaneously in some circumstances" (p. 48), but remark that not both emotions are felt strongly when being present simultaneously. Instead, they propose that "one response (i.e., the dominant response; e.g., sadness) is usually stronger than the semantically opposite response (i.e., the conflicting response; e.g., happiness)" (p. 48). Interestingly, in the case of the major seventh chord, listeners perceived more *melancholy/sadness* than *happiness/joy* in the chord, and the mixed emotion of *nostalgia/longing* seemed to capture the chord's affective quality better than either of the two aforementioned dimensions representing basic emotions (Lahdelma & Eerola, 2014).

The *clashing conventions* explanation needs certain premises to have thorough explanatory power, however. If the concurrence of the major triad and a minor second/major seventh would always create nostalgia, a dissonant chord like the major triad with an added augmented fifth (C-E-G-G#) should sound "nostalgic" as well. Intuitively this is, of course, not the case: instead of sounding nostalgic the chord is highly unstable due to its interval distribution, namely the concurrence of two major thirds (C-E and E-G#). Meyer (1956) proposes that augmented and diminished triads produce ambiguity because of their "intervallic equidistance" (p. 164), an even spacing between the tones in the chord. He points out that these chords are identified with affectivity and are often "used to express intense emotion, apprehension, and anxiety" (p. 164). However, this effect can perhaps be better explained with the concept of *tonal dissonance*. Johnson-Laird et al. (2012) propose that the perception of dissonance in music can be explained with a *dual-process theory of dissonance*. They suggest that dissonance

> results from a combination of sensory and tonal dissonance, where 'sensory' dissonance arises…in particular from roughness (i.e., the rapid beating of partials), and 'tonal' dissonance is a consequence of high-level cognitive processes that rely on a tacit knowledge of the principles of tonality. (p. 24)

They propose that tonal dissonance depends on the scales in which the chords can occur:

> Chords occurring in a major scale should be less dissonant than chords occurring only in a minor scale, which in turn should be less dissonant than chords occurring in neither sort of scale. (p. 24)

Finally, they suggest that

> chords that are consistent with a major triad are more consonant than chords that are not consistent with a major triad…hence, a chord of a seventh, such as GBDF, is consistent with a major triad (GBD) because the seventh, F, occurs in a major scale in which the triad also occurs (the scale of C major), whereas a chord, such as GBDEb, is not consistent with a major triad because the added note does not occur in a major scale containing the major triad. (p. 24)

Obviously, these principles should then logically bear on the emotion perception of single chords, as well as on their perceived amount of dissonance.

The low amount of tonal dissonance is an essential premise for the *clashing conventions* explanation. In relation to a C major triad there are only three possible minor seconds (the major sevenths can be regarded as the inversions of the minor seconds) that would create minimal tonal dissonance (those minor seconds that are present in major diatonic scales): E-F, B-C and F#-G. So, this narrows the possible combinations of the concurrence of a major triad and a minor second (and their respective inversions) within diatonic major scale contexts to the following sets of tones: C-E-G-B (a major triad with an added major seventh, present in C major and in G major), C-E-F-G (a major triad with an added fourth, present in C major and in F major), and the unusual chord of C-E-F#-G (a major triad with an added augmented fourth, present theoretically in G major). The major triad with an added fourth contains more roughness than the major seventh chord (Figure 1), yet the added fourth chord would intuitively seem to convey less nostalgia than the major seventh chord. We propose that this might be explained by the difference in the amount of harmonicity the chords contain: the major triad with an added fourth has higher harmonicity than the major seventh chord (Figure 2). As F can be seen as a missing fundamental of the C major triad (Parncutt, 2012), B is arguably simply more "alien" in the C major triad's context than F. It can be argued that a larger amount of harmonicity could indeed create more positive valence as, according to Parncutt (2012), it also creates more consonance. According to a similar logic, the major seventh chord could in turn create slightly more "negative valence" and hence nostalgia than the added fourth chord, as in addition to the clashing of the affective indices (major triad as an index of happiness, the minor second/major seventh of negative valence), B is a more distant tone within a C major triad context than F. In Parncutt's (1993) experiment, listeners rated how well probe tones went with preceding chords. In regard to the major triad, the probe tone of the perfect fourth was rated to fit the major triad better than the major seventh.

The same holds true for the major triad with an added augmented fourth: it is not rough (Figure 1) and has low tonal dissonance, but what makes it "un-nostalgic" is the high amount of harmonicity it contains (Figure 2). It is also intriguing to have a look at the dominant seventh triad as well, as it could also be seen as an example of a "clashing convention": in its root position (C-E-G-Bb) it is a major triad (C-E-G) with an added minor third (G-Bb). According to Cooke (1959) this clash is what gives the chord its "sad and empty sound" (p. 74), stemming from the "undermining of the normal joyful feeling of the major triad supporting it" (p. 74), a view that obtained no empirical support in the study of Lahdelma and Eerola (2014). The chord has a strikingly low amount of roughness (Figure 1), has no tonal dissonance and contains a high amount of harmonicity (Figure 2). Also, Parncutt (2014) suggests that the dominant seventh "looks like a part of the harmonic series," as "the difference between the 'harmonic' ('natural', 'septimal') minor 7th (7:4, 969 cents) and the minor seventh in 12-tone equal temperament (1000 cents) lies within the tuning tolerance of the auditory system for recognizing harmonic patterns" (p. 328). Again, we surmise that the higher amount of harmonicity results in a lower amount of perceived nostalgia: the dominant seventh was not rated as nostalgic according to the data of Lahdelma and Eerola (2014). Interestingly, the moderately nostalgic minor seventh chord (Lahdelma & Eerola, 2014) also has only a medium amount of harmonicity (Figure 2). The nostalgia predictions of selected chords and the amount of tonal dissonance, harmonicity, and roughness they contain can be seen in Table 1.

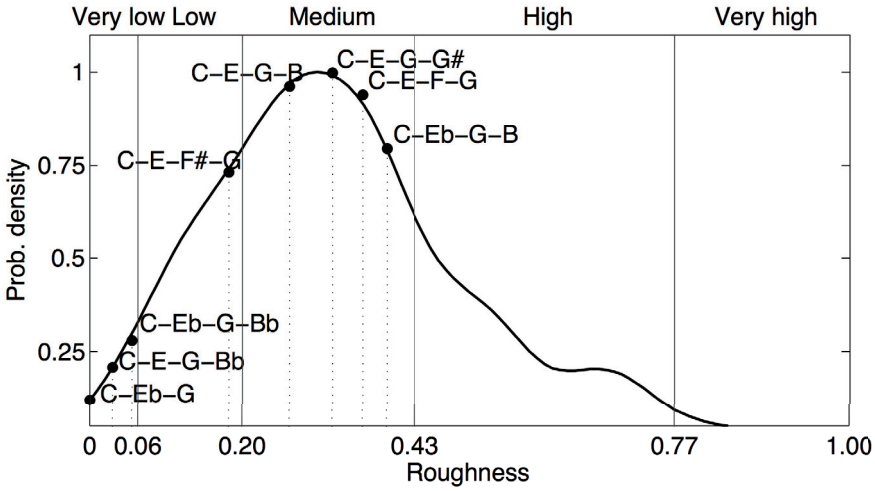

Fig. 1. Roughness as a probability density of all four-tone chords within an octave, with eight example chords highlighted.

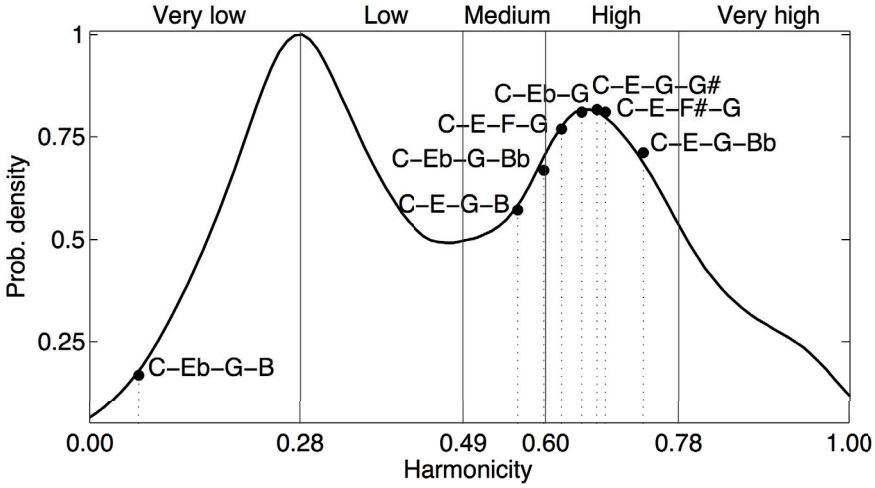

Fig. 2. Harmonicity as a probability density of all four-tone chords within an octave, with eight example chords highlighted.

The psychoacoustic predictions were estimated by first creating all possible four-tone chords within an octave (resulting in 536 separate chords, discounting the inversions). These chords (and one three-tone chord, C-Eb-G, for a reference) were implemented as a combination of four equally loud fundamentals that were transformed into complex sounds with Shepard spectra using MIDI toolbox (Eerola & Toiviainen, 2003). These sounds were in turn analyzed with MIR toolbox (version 1.5) for harmonicity (Jensen, 1999) and roughness (Vassilakis, 2001). Since this analysis yielded a broad range of values which by themselves are not meaningful unless used in a context, the output was set to vary between 0 and 1 and the feature histograms were converted into probability densities. From these, the quantiles were used to simplify and express the values from Very low to Very high (see Figure 1 and 2 for the quantile boundaries and individual chord values, whereas Table 1 displays only the value categories). In Table 1, the tonal dissonances are empirically reported values taken from Johnson-Laird et al. (2012).

Table 1. Theoretical predictions of nostalgia and musical/psychoacoustic attributes of selected chords (in middle register voicings with Shepard tones).

No.	Chord	Nostalgia prediction	Tonal dissonance	Harmonicity	Roughness
1	C-E-G-B	High	Low	Medium	Medium
2	C-E-F-G	Moderate	Low	High	Medium
3	C-E-G-G#	Low	High	High	Medium
4	C-Eb-G-B	Low	Medium	Very low	Medium
5	C-Eb-G-Bb	Moderate	Low	Medium	Very low
6	C-Eb-G	High	Low	High	Very low
7	C-E-G-Bb	Low	Low	High	Very low
8	C-E-F#-G	Low	Low	High	Low

SUGGESTIONS FOR EMPIRICAL EXPERIMENTS

No direct empirical tests have yet been conducted on the issue of how vertical harmony is able to convey nostalgia. To disentangle which of the current study's proposed explanations would prevail and whether some of these explanations would be more valid in the case of certain chords than others, further empirical experiments are needed. Also, a broad chord palette including chords that were not tested in the study of Lahdelma and Eerola (2014) could help in further investigating the question of vertical harmony being able to convey nostalgia and longing. Cooke (1959), for example, proposes that the major sixth chord is able to create "pleasurable longing" (p. 69), and suggests that the dominant thirteenth chord has a "yearning" quality (p. 70). Tagg and Clarida (2003) propose that the added major ninth in minor triads embodies qualities of "the bitter-sweet, sad lonely and longing, at least in European classical (chiefly romantic) music, as well as in the idiom of traditional film music" (p. 577).

In the major seventh chord's case it is intriguing to test which of the proposed explanations (*learning*, *intrinsic emotional meaning built into tonality* or *clashing conventions*) might better explain its ability to convey nostalgia. Intuitively, a simple test of also playing the minor major seventh chord (C-Eb-G-B) to the participants could tell more about the validity of the "iconic" longing Cooke attributes to the leading tone - whether the leading tone indeed conveys longing iconically in vertical harmony (single chords) as well. Cooke's theory would certainly imply that the leading tone would be longing to the tonic in the minor major seventh chord as well: after all, if horizontal harmony would indeed affect chord perception in this way, the leading or aspiring "quale" of the seventh tone would surely be learned from the harmonic or (ascending) melodic minor scale's leading tone as well as from the major scale. Cooke (1959) actually makes clear that he is omitting certain chords' emotional connotations (for example the "minor-triad-plus-major-sixth") and although not mentioning it directly, also the minor major seventh chord, in order to confine his investigation to "basic elements" of what he calls "the language of music" (p. 72). From a present-day scholar's view this looks somewhat like an attempt on Cooke's behalf not to contradict

himself. The authors surmise that the minor major seventh chord would not convey nostalgia in any effective way because of the chord's tonal dissonance; Johnson-Laird et al. (2012) suggest that in principle

> the chords of major sevenths (e.g., CEGB), minor sevenths (e.g., DFAC), sevenths (e.g., GBDF), and half-diminished sevenths (e.g., BDFA) occur in major scales and so they should be less dissonant than minor triads with major sevenths, e.g., ACEG#, augmented triads with a major sevenths (e.g., CEG#B) and diminished sevenths (e.g. AbFBD), which occur only in minor scales. (p. 24)

Also, the minor major seventh has a considerably higher amount of roughness than the major seventh chord (Figure 1), and has a very low amount of harmonicity (Figure 2). The minor major seventh chord's higher tonal dissonance, roughness and very low harmonicity seem to result in a rather "dark" and "sinister" voicing (technically also a clashing of the minor triad [C-Eb-G] and the major third [G-B], its emotional effect yet to be tested empirically). The chord is notorious for its use in, for example, Bernard Herrmann's film score for Alfred Hitchcock's classic horror-thriller *Psycho* (1960), and has been referred to as the "Hitchcock-chord" (Brown, 1994), underlining its ominous quality.

DISCUSSION

Our aim was to account for the empirical findings of Lahdelma and Eerola (2014), according to which certain single, isolated chords (minor triads, minor sevenths and especially major sevenths) are moderately effective at conveying the mixed, complex emotion of nostalgia. These results raise the question whether there is a possibility that nostalgia in music is not necessarily related only to *episodic memory* (extra-musical connotations), but that it can be conveyed even by abstract, reduced stimuli such as single chords outside a musical and tonal context. To account for this finding, we outlined three different candidate explanations, including (1) *learning*, (2) *intrinsic emotional connotations arising from tonal relations*, and (3) *clashing conventions*. The question of which one of the outlined explanations bears the most explanatory power will have to be dealt with in further empirical experiments. It is clear, however, that the suitability of the explanations seem to depend also on the chord in question. We surmise that with the minor triad the *learning* theory could be the most probable explanation, as with a single triad there are no "intrinsic" meanings built into the chord, be it *emotional connotations arising from tonal relations* or the current authors' theory of *clashing conventions*. In addition to the minor mode (Tagg & Clarida, 2003), the isolated minor triad also seems to be affiliated with sadness, melancholy, and also nostalgia. However, in addition to the learning perspective, there exists the possibility that psychoacoustics could affect the emotion perception of the minor triad as well, although the amount of roughness and harmonicity the minor triad contains is quite similar to that of the major triad if one considers a wide range of different sonorities. According to Parncutt (2014), the minor triad has a more ambiguous main pitch or root than the major triad; curiously, Tagg and Clarida (2003) suggest that in the emotion of longing there is also an inherent "uncertainty." Could this ambiguity of the root in the minor triad when compared to the major triad lead to associations of nostalgia and longing as well?

Nostalgia in itself is a culturally loaded and a quite ambiguous term, which can also be seen from the subtle differences between US and Finnish respondents in regard to this particular emotion (Lahdelma & Eerola, 2014). Also, while the double term "nostalgia/longing" is somewhat robust, this umbrella term made it possible to gather the original data (Lahdelma & Eerola, 2014) on a level that was delicate enough to showcase clear differences and underlying patterns, but was not so subtle so as to create too much diversion that could not have been interpreted in a meaningful way. As the music analytical examples from the literature show, there seems to be a definite connection between major seventh harmony and the emotions of "nostalgia" and "longing" along a music historical continuum. While subtle variations of the dimension may not be possible to capture with this umbrella term, it is quite remarkable that listeners did articulate and agree on this original label term as much as they did, especially with regard to the amount of *nostalgia/longing* perceived in the major seventh chord. The more subtle the variations under the umbrella term would be, the more individual differences between respondents we would be likely to find – with language and culture also affecting the responses more.

We see that in order to minimize the effect of possible emotion term confusions, future experiments could also distinguish between *nostalgia* and *longing*, to test if there are any differences to be found between these two emotion terms and whether one or the other actually captures the affective

qualities of particular chords better. In regard to the study by Lahdelma and Eerola (2014), it is at this point unclear whether perceived nostalgia would hold up also with open questions, as opposed to pre-selected emotion terms, in the experiment design. However, according to their study a most interesting case in point concerning single chords' ability to convey the complex and mixed emotion of nostalgia is the major seventh chord. As the major seventh chord's third inversion's mean rating (when played in string timbre) was highest on the dimension of nostalgia of all the given emotion dimensions, it begs the question of how this particular chord is able to convey nostalgia so effectively. With string instruments the average ratings for the dimension of *nostalgia/longing* were somewhat higher than with the piano, suggesting the fact that the strings' soft timbre with a slow attack --as opposed to the piano's loud, sharp attack with a fast decay-- convey this particular emotion more efficiently. Naturally, far from being a completely "fixed" and "lexical" meaning of nostalgia and longing, the major seventh chord is obviously subordinate to psychophysical (tempo, dynamics, phrasing) parameters as well, especially in actual music—just like the major and minor triads with regard to "happiness" and "sadness," respectively (Gabrielsson & Lindström, 2010).

While it is not yet possible to entirely dismiss Cooke's (1959) theory of the major seventh chord's emotional properties arising from intrinsic tonal relations, this theory certainly has its flaws. Accordingly, the learning aspect also cannot be ruled out at this point, as there is a possibility that the major seventh chord's nostalgic connotation stems from learning and that this chord has simply been used in the context of music that the respondents somehow recall. In other words, the possibility of the major seventh chord being a case of *evaluative conditioning* just like the "indices" of the "happy" major and "sad" minor triads cannot be ruled out. According to this line of thinking, however, nearly all tonal chords should sound more or less "nostalgic," as they have been heard countless times in all kinds of settings. According to the empirical data of Lahdelma and Eerola (2014) this is clearly not the case, as only three chords were effective at conveying this particular emotion. In the minor seventh chord's case the question is whether its nostalgic connotation arises from the minor triad that is present in the chord, or whether the added minor seventh tone has something to do with its conveyed nostalgia. However, while the minor seventh was above average in its power to convey nostalgia, it was not as effective in this as the minor triad or the major seventh chord.

The possible interaction between the three proposed candidate explanations is also something to be considered. For example, by combining two of the proposed mechanisms, namely the (1) *learning* aspect with Cooke's (1959) proposal of certain chord's emotional properties arising from (2) *tonal relations*, the major seventh chord's nostalgic connotations might arise from a combination of these two. The leading tone's "longing" in relation to the major triad (also as an appoggiatura) might be learned from an extensive exposure to tonality. The dissonance in the major seventh chord, for example, can suggest a need to resolve without actually resolving. Interestingly, Toch (1948) proposes that imaginary motion gives meaning to audible symbols, referring to vertical harmony as "arrested motion" (p. 22). Thus, the thorough conditioning to voice leading processes could also be affecting the way an isolated chord is perceived. The minor major seventh chord's theoretical case of sounding rather "un-nostalgic," however, seems to somewhat challenge this view: while the major seventh in addition to the minor triad should accordingly suggest a need to resolve, the overall (isolated) sonority would probably not convey nostalgia or longing in any effective way because of the chord's relatively high (both sensory and tonal) dissonance, as discussed earlier. Consequently, the most salient difference between Cooke's and the current authors' theories is that, in sum, the *clashing conventions* explanation does not grant the leading tone any affective "quale" per se within the chord. Instead, we surmise that Cooke possibly *misattributes* the major seventh chord's nostalgia to the "longing" of the leading tone towards the tonic. However, the question of the role of a possible interaction between vertical and horizontal harmony with regard to nostalgia and longing in music should be investigated more thoroughly with future experiments.

It is interesting to compare the case of the virtually common-knowledge major triad-happy, minor triad-sad affective convention with some of the not so "well-conventionalized" seventh chords. The major and minor triads are extremely effective at conveying happiness/joy and melancholy/sadness (basic emotions) respectively, while the chord of the major seventh seems to be conveying the mixed emotion of nostalgia quite effectively, but slightly more ambiguously. As, from a psychological perspective, all perception depends on learning (Gibson, 1969), a crucial question is whether the effectively learned (by enculturation) two distinct "indices," i.e. the major triad as the index of happiness/joy, the minor second and its inversion as the index of melancholy/sadness might be able to create new, complex emotional meaning (nostalgia) when present concurrently in the major seventh chord. Or is the major seventh chord's

nostalgic connotation learned per se, without any cognitive involvement in its emotional evaluation? The former view is in sharp contrast with the view of, for example, Terhardt (1974) who proposes that single isolated chords are judged on the basis of sensory consonance, and that there is nothing cognitive involved in this process (as opposed to the perception of horizontal harmony). Nostalgia, however, is not necessarily only confined to cognitive rumination: as a parallel to real-life nostalgia, it is interesting to think about how, for example, odors are able to create nostalgia directly without cognitive appraisal (Hirsch, 1992). The raised question might be relevant not only to the study of music psychology and musicology, but also to the study of emotions in general.

Parncutt (2012) suggests that the consonance/dissonance of Western sonorities is based on a combination of roughness, harmonicity and familiarity. We surmise that the same could well hold true also with regard to single chords' emotional impact, as not only roughness, but also harmonicity and tonal dissonance seem to affect emotional evaluations of single chords. After all, as Parncutt and Hair (2011) aptly put it, "harmony is an experience that lies at the interface between sensation and emotion" (p. 161). The tentative measurements of roughness and harmonicity in single chords compared to the existing empirical results of Lahdelma and Eerola (2014) suggest that the emotion perception of single chords and certain chords' ability to convey the mixed, complex emotion of nostalgia might be a delicate combination of cultural conventions and psychoacoustic phenomena, as well as learning. To shed light on this fascinating and elusive question, more empirical experiments are needed.

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NOTES

[1] Corresponding Author. University of Jyvaskyla, Department of Music, P.O. Box 35, (M), FI-40014 University of Jyvaskyla, Finland. Email: imre.d.lahdelma@student.jyu.fi

REFERENCES

Bakker, D.R., & Martin, F.H. (2015). Musical chords and emotion: Major and minor triads are processed for emotion. *Cognitive, Affective, & Behavioral Neuroscience, 15*, 15−31.

Barrett, F.S., Grimm, K.J., Robins, R.W., Wildschut, T., Sedikides, C., & Janata, P. (2010). Music-evoked nostalgia: Affect, memory, and personality. *American Psychological Association, 10,* 309−403.

Batcho, K.I. (2007). Nostalgia and the emotional tone and contents of song lyrics. *The American Journal of Psychology, 120*, 361−381.

BBC (2011). *BBC Proms 2011: Mahler - Adagietto from Symphony No. 5 from Prom 69*. Retrieved from http://www.bbc.co.uk/programmes/p00k9fcg

Bernstein, L. (1976). *The unanswered question: Six talks at Harvard*. Cambridge, MA: Harvard University Press.

Bigand, E., Vieillard, S., Madurell, F., Marozeau, J., & Dacquet, A. (2005). Multidimensional scaling of emotional responses to music: The effect of musical expertise and of the duration of the excerpts. *Cognition and Emotion, 19*, 1113−1139.

Bowling, D.L., Gill, K., Choi, J.D., Prinz, J. & Purves, D. (2010). Major and minor music compared to excited and subdued speech. *Journal of the Acoustical Society of America, 127*, 491−503.

Boym, S. (2001). *The future of nostalgia*. New York: Basic Books.

Brown, R.S. (1994). *Overtones and undertones: Reading film music.* Berkeley, CA: University of California Press.

Cheung, W., Wildschut, T., Sedikides, C., Hepper, E. G., Arndt, J., & Vingerhoets, A. J. J. M. (2013). Back to the future: Nostalgia increases optimism. *Personality and Social Psychology Bulletin, 39*, 1484−1496.

Cohen, A.J. (2010). Music as a source of emotion in film. In Juslin, P. and Sloboda, J. (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 879−908). Oxford: Oxford University Press.

Cooke, D. (1959). *The language of music*. Oxford: Oxford University Press.

Costa, M., Bitti, P. & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music, 28*, 4−22.

Cousineau, M., McDermott, J., & Peretz, I. (2012). The basis of musical consonance as revealed by congenital amusia. *Proceedings of the National Academy of Sciences, 109*, 19858−19863.

Crowder, R. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology, 4,* 3−10.

Curtis, M., & Bharucha, J. (2010). The minor third communicates sadness in speech, mirroring its use in music. *Emotion, 10(3)*, 335−348.

Dalla Bella, S., Peretz, I., Rousseau, L., & Gosselin, N. (2001). A developmental study of the affective value of tempo and mode in music. *Cognition, 80*, B1–10.

Eerola, T. & Toiviainen, P. (2003). *MIDI toolbox: MATLAB tools for music research*. Jyväskylä, Finland: University of Jyväskylä.

Eerola, T., Alluri, V., & Ferrer, R. (2012). Timbre and affect dimensions: Evidence from affect and similarity ratings and acoustic correlates of isolated instrument sounds. *Music Perception, 30(1)*, 49−70.

Everett, W. (2008). *The foundations of rock: From "Blue Suede Shoes" to "Suite: Judy Blue Eyes"*. New York: Oxford University Press.

Filipic, S., Tillmann, B., & Bigand, E. (2010). Judging familiarity and emotion from very brief musical excerpts. *Psychonomic Bulletin & Review, 17(3)*, 335–341.

Fleming, W., & Veinus, A. (1958). *Understanding music: Style, structure, and history*. New York: Holt, Rinehart and Winston.

Freeman, J.W. (1992). The language of longing: Only at the final cadence does "Parsifal" resolve its musical question. *Opera News, 56,* 26−29.

Gabriel, C. (1978). An experimental study of Deryck Cooke's theory of music and meaning. *Psychology of Music, 6*, 13–20.

Gabrielsson, A., & Lindström, E. (2010). The role of structure in the musical expression of emotions. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 393–414). Oxford, UK: Oxford University Press.

Gibson, E.J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.

Helmholtz, H. (1895/1980). *On the sensations of tone as a physiological basis for the theory of music* (A. Ellis, Trans.). New York: Dover.

Hindemith, P. (1942). *The Craft of Musical Composition: Book 1−Theoretical Part* (A. Mendel, Trans.). New York: Associated Music Publishers.

Hirsch, A.R. (1992). Nostalgia: A neuropsychiatric understanding. *Advances in Consumer Research, 19*, 390−395.

Hunter, P.G., Schellenberg, E.G., & Schimmack, U. (2010). Feelings and perceptions of happiness and sadness induced by music: Similarities, differences, and mixed emotions. *Psychology of Aesthetics, Creativity, and the Arts, 4(1)*, 47–56.

Huron, D. (2006). *Sweet anticipation: Music and the psychology of expectation*. Cambridge, MA: MIT Press.

Huron, D. (2008). A comparison of average pitch height and interval size in major- and minor-key themes: Evidence consistent with affect-related pitch prosody. *Empirical Musicology Review, 3*, 59–63.

Huron, D., & Davis, M.J. (2012). The harmonic minor scale provides an optimum way of reducing average melodic interval size consistent with sad affect cues. *Empirical Music Review, 7,* 103−117.

Hutchinson, W., & Knopoff, L. (1979). The significance of the acoustic component of consonance in Western triads. *Journal of Musicological Research, 3*, 5−22.

Janata, P.J., Tomic, S.T., & Rakowski, S.K. (2007). Characterization of music-evoked autobiographical memories. *Memory, 15*, 845–860.

Jensen, T. (1999). *Timbre Models of Musical Sounds*, Rapport 99/7. Copenhagen, Denmark: University of Copenhagen.

Johnson-Laird, P.N., Kang, O.E. & Leong, Y.C. (2012). On musical dissonance. *Music Perception, 30(1)*, 19–35.

Juhl, J., & Routledge, C. (2013). Nostalgia bolsters perceptions of a meaningful self in a meaningful world. In J. Hicks & C. Routledge (Eds.), *The experience of meaning in life: Perspectives from the psychological sciences* (pp. 213–226). New York: Springer Press.

Juslin, P. (2011). Music and emotion: Seven questions, seven answers. In I. Deliège & J. Davidson (Eds.), *Music and the mind: Essays in honour of John Sloboda* (pp. 113−135). New York: Oxford University Press.

Juslin, P. (2013). What does music express? Basic emotions and beyond. *Frontiers in Emotion Science, 4 (article 596),* 1−14.

Juslin, P., Harmat, L., & Eerola, T. (2013). What makes music emotionally significant? Exploring the underlying mechanisms. *Psychology of Music*, *42,* 599−623.

Juslin, P. N., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code? *Psychological Bulletin, 129*, 770−814.

Juslin, P., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research, 33*, 217−238.

Juslin, P., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). An experience sampling study of emotional reactions to music: Listener, music, and situation. *Emotion, 8*, 668−683.

Juslin, P., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences, 31*, 559−621.

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory. Part 1: Consonance of dyads. *Journal of the Acoustical Society of America, 45*, 1451−1459.

Kaminska, Z., & Woolf, J. (2000). Melodic line and emotion: Cooke's theory revisited. *Psychology of Music, 28*, 133−153.

Kelly, B.L. (2001). "Ravel, (Joseph) Maurice." *Grove Music Online*. Edited by Deane Root. http://www.oxfordmusiconline.com (Accessed 17 November 2014).

Key, S. (1995). Sound and sentimentality: Nostalgia in the songs of Stephen Foster. *American Music, 13(2)*, 145−166.

Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition.* Evanston, IL: Northwestern University.

Krumhansl, C. (1990). *Cognitive foundations of musical pitch*. New York: Oxford University Press.

Lahdelma, I., & Eerola, T. (2014). Single chords convey distinct emotional qualities to both naïve and expert listeners. *Psychology of Music, doi:10.1177/0305735614552006.*

Laukka, P., Eerola, T., Thingujam, N. S., Yamasaki, T., & Beller, G. (2013). Universal and culture-specific factors in the recognition and performance of musical affect expressions. *Emotion, 13*, 434−449.

Maher, T. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *American Journal of Psychology, 93,* 309−327.

Malin, Y. (2006). Metric displacement dissonance and romantic longing in the German Lied. *Music Analysis, 25(3)*, 251−288.

Malmberg, C. F. (1918). The perception of consonance and dissonance. *Psychological Monographs, 25(2)*, 93–133.

McDermott, J., Lehr, A., & Oxenham, A. (2010). Individual differences reveal the basis of consonance. *Current Biology, 20*, 1035–1041.

Meyer, L.B. (1956). *Emotion and meaning in music*. Chicago: The University of Chicago Press.

Mitchell, D. (2002). Eternity or nothingness? Mahler's Fifth Symphony. In D. Mitchell & A. Nicholson (Eds.), *The Mahler Companion* (pp. 236–325). New York: Oxford University Press.

Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing, 10(2),* 113−131.

Pallesen, K., Brattico, E., Bailey, C., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2005). Emotion processing of major, minor, and dissonant chords: A functional magnetic resonance imaging study. *Annals of the New York Academy of Sciences, 1060*, 450−453.

Parncutt, R. (1993). Pitch properties of chords of octave-spaced tones. *Contemporary Music Review, 9*, 35–50.

Parncutt, R. (1989). *Harmony: A psychoacoustical approach*. Berlin, Germany: Springer-Verlag.

Parncutt, R. (2011). The tonic as triad: Key profiles as pitch salience profiles of tonic triads. *Music Perception, 28*, 333–365.

Parncutt, R. (2012). Major-minor tonality, Schenkerian prolongation, and emotion: A commentary on Huron and Davis (2012). *Empirical Music Review, 7*, 118−137.

Parncutt, R. (2014). The emotional connotations of major versus minor tonality: One or more origins? *Musicae Scientiae, 18(3)*, 324−353.

Parncutt, R., & Hair, G. (2011). Consonance and dissonance in theory and psychology: Disentangling dissonant dichotomies. *Journal of Interdisciplinary Music Studies, 5*, 119–166.

Peretz, I. (2010). Towards a neurobiology of musical emotions. In Juslin, P. & Sloboda, J. (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 99−126). Oxford: Oxford University Press.

Schenker, H. (1906). *Harmonielehre (Neue musikalische Theorien und Phantasien, Vol. 1)*. Stuttgart: J. G. Cotta.

Scherer, K. R. (1986). Vocal affect expression: A review and a model for future research. *Psychological Bulletin, 99*, 143–165.

Schoenberg, A. (1922/1990). *Theory of harmony* (Roy E. Carter, Trans.). London: Faber and Faber.

Schubert, E. (2010). Continuous self-report methods. In Juslin, P. & Sloboda, J. (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 223–253). Oxford: Oxford University Press.

Sedikides, C., Wildschut, T., Arndt, J., & Routledge, C. (2008). Nostalgia: Past, present, and future. *Current Directions in Psychological Science, 17*, 304–307.

Sedikides, C., Wildschut, T., & Baden, D. (2004). Nostalgia: Conceptual issues and existential functions. In J. Greenberg, S. Koole, & T. Pyszczynski (Eds.), *Handbook of experimental existential psychology* (pp. 200–214). New York, NY: Guilford Press.

Spencer, H. (1857). The origin and function of music. *Fraser's Magazine, 56*, 396–408.

Tagg, P. (1993). 'Universal' music and the case of death. http://www.tagg.org/articles/xpdfs/deathmus.pdf (Accessed 17 November 2014).

Tagg, P., & Clarida, B. (2003). *Ten little title tunes: Towards a musicology of the mass media*. New York: The Mass Media Music Scholars' Press.

Taruffi, L., Koelsch, S. (2014). The paradox of music-evoked sadness: An online survey. *PLoS ONE 9(10)*: e110490. doi: 10.1371/journal.pone.0110490

Terhardt, E. (1974). On the perception of periodic sound fluctuations (roughness). *Acustica*, *30*, 201−213.

The New Oxford Dictionary of English (1998). Oxford: Oxford University Press.

Tillman, B., Bharucha, J.J., & Bigand, E. (2000). Implicit learning of tonality: A self-organizing approach. *Psychological Review, 107(4)*, 885−913.

Toch, E. (1948). *The shaping forces in music*. New York: Criterion Music Corp.

Tramo, M.J., Cariani, P.A., Delgutte, B., & Braida, L.D. (2001). Neurobiological foundations for the theory of harmony in western tonal music. *Annals of the New York Academy of Sciences, 930*, 92−116.

Vassilakis P. N. (2001). *Perceptual and physical properties of amplitude fluctuation and their musical significance* (Unpublished doctoral dissertation). University of California, Los Angeles.

Werman, D. S. (1977). Normal and pathological nostalgia. *Journal of the American Psychoanalytic Association, 25*, 387−398.

Virtala, P., Huotilainen, M., Partanen, E., Fellman, V., & Tervaniemi, M. (2013). Newborn infants' auditory system is sensitive to Western music chord categories. *Frontiers in Auditory Cognitive Neuroscience, 4, 462*, 1−10.

Wildschut, T., Sedikides, C., Arndt, J., & Routledge, C. (2006). Nostalgia: Content, triggers, functions. *Journal of Personality and Social Psychology, 91*, 975−993.

Wildschut, T., Sedikides, C. & Routledge, C. (2008). Nostalgia: From cowbells to the meaning of life. *The Psychologist, 21*, 20−23.

Zentner, M., Grandjean, D., & Scherer, K. (2008). Emotions evoked by the sound of music: Characterization, classification, and measurement. *Emotion, 8*, 494−521.

Zentner, M., & Eerola, T. (2010). Self-report measures and models of musical emotions. In Juslin, P. & Sloboda, J. (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 187−221). Oxford: Oxford University Press.

Zentner, M. & Kagan, J. (1996). Perception of music by infants. *Nature, 383*, 29.

III

MILD DISSONANCE PREFERRED OVER CONSONANCE IN SINGLE CHORD PERCEPTION

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Mild Dissonance Preferred Over Consonance in Single Chord Perception

Imre Lahdelma
University of Jyväskylä, Finland; University of Washington, USA

Tuomas Eerola
Durham University, UK

Abstract

Previous research on harmony perception has mainly been concerned with horizontal aspects of harmony, turning less attention to how listeners perceive psychoacoustic qualities and emotions in single isolated chords. A recent study found mild dissonances to be more preferred than consonances in single chord perception, although the authors did not systematically vary register and consonance in their study; these omissions were explored here. An online empirical experiment was conducted where participants ($N = 410$) evaluated chords on the dimensions of Valence, Tension, Energy, Consonance, and Preference; 15 different chords were played with piano timbre across two octaves. The results suggest significant differences on all dimensions across chord types, and a strong correlation between perceived dissonance and tension. The register and inversions contributed to the evaluations significantly, nonmusicians distinguishing between triadic inversions similarly to musicians. The mildly dissonant minor ninth, major ninth, and minor seventh chords were rated highest for preference, regardless of musical sophistication. The role of theoretical explanations such as aggregate dyadic consonance, the inverted-U hypothesis, and psychoacoustic roughness, harmonicity, and sharpness will be discussed to account for the preference of mild dissonance over consonance in single chord perception.

Keywords

chord, vertical harmony, consonance/dissonance, psychoacoustics, preference

Introduction

Research on harmony perception has predominantly been concerned with harmony's *horizontal* dimension in the form of harmonic progressions (e.g., Bigand & Parncutt, 1999; Bigand, Parncutt & Lerdahl, 1996; Sloboda, 1991; Webster & Weir, 2005). Considerably less attention has been turned to harmony's *vertical* dimension, that is, how listeners perceive

Corresponding author:
Imre Lahdelma, Department of Music, University of Jyvaskyla, P.O. Box 35, FI 40014, Finland.
Email: imre.lahdelma@jyu.fi

single chords (three or more simultaneous pitches) isolated from all musical context. As Huron (1994) notes: "little is known about the perception of three or more concurrent pitches ..." (p. 304) and Gabrielsson and Lindström (2010) concur: "... there is practically nothing on how different kinds of chords ... may affect expression" (p. 393).

While there have been some empirical studies conducted on specifically vertical harmony perception, the emphasis has been mainly on harmonic intervals (e.g., Costa, Bitti, & Bonfiglioli, 2000; Krantz, Merker, & Madison, 2004; Maher, 1980; Oelmann & Laeng, 2009), on the major or minor triad distinction (e.g., Bakker & Martin, 2015; Crowder, 1985; Heinlein, 1928; Kastner & Crowder, 1990), or on the perception of consonance or dissonance mostly in triads (e.g., Bidelman & Krishnan, 2011; Cook, 1999; Pallesen et al., 2005; Roberts, 1986). Research addressing the perception of chords containing more than three pitches has been rare: Studies focusing directly on single chord perception while using a more diverse chord palette have been conducted by Minati et al. (2009) who applied tetrads in a neurological experiment on consonance or dissonance perception; Kuusi (2010, 2011) who investigated how listeners perceive nontraditional (nontonal) chords; and by Lahdelma and Eerola (2016) who focused exclusively on the emotion perception of single chords, spanning both triads and seventh chords.

As Parncutt (1989) puts it, "musical sounds are consonant if they are perceived to 'sound well' with each other (*con sonare*), and suggests that "chords are consonant if they contain no dissonant intervals" (p. 56). Consonance or dissonance can be divided into two subcategories: Single isolated intervals and chords represent *sensory consonance or dissonance* (psychoacoustics), while consonance or dissonance in chords and intervals while being part of a musical context is referred to as *musical consonance or dissonance* or *musical acoustics* (e.g., Krumhansl, 1990; Terhardt, 1984; Zwicker & Fastl, 1990).

It is widely held that sensory dissonance arises from the beating of frequency components (e.g., Hutchinson & Knopoff, 1978; Kameoka & Kuriyagawa, 1969). According to McDermott, Lehr, and Oxenham (2010) "beating occurs whenever two sinusoids of differing frequency are combined" (p. 1), which in turn creates the sound quality of *roughness* that listeners typically perceive as unpleasant. The effect of roughness is seen as prevalent in dissonant, but not in consonant musical chords (e.g., Hutchinson & Knopoff, 1978; Plomp & Levelt, 1965). Zentner and Kagan (1998) propose that the preferential bias for consonance could be innate, basing this view on their finding that infants are biologically prepared to treat consonance as more pleasant than dissonance; this view of an innate preference for consonance, however, has later been challenged by Plantinga and Trehub (2014).

Zwicker and Fastl (1990, p. 313) point out three actual factors that contribute to sensory consonance or dissonance: (a) *roughness*, (b) *sharpness*, and (c) *tonalness* (in contrast to noisiness). More recent studies (Cousineau, McDermott, & Peretz, 2012; McDermott et al., 2010), however, suggest that *harmonicity*, that is, "the extent that the sonority's audible spectrum corresponds to a harmonic series" (Parncutt, 2014a, p. 972) plays also an important role in the perception of consonance or dissonance, possibly an even more important one than roughness. According to this view, "consonant chords derive their pleasantness not from the absence of beating, but rather from their similarity to single notes with harmonic spectra" (McDermott et al., 2010, p. 2). The study by McDermott et al. (2010) curiously indicates that harmonicity preferences correlate with musical expertise, suggesting that exposure to music amplifies preferences for harmonic frequencies because of their musical importance.

According to the results of Lahdelma and Eerola (2016), chords that are considered as mildly dissonant in terms of both *sensory* (i.e., chords containing dissonant intervals) as well

as *musical* consonance or dissonance (see e.g., Révész, 1954) were actually the most preferred ones among a heterogeneous and big sample of listeners including both experts and inexperts: The mildly dissonant minor seventh and major seventh chords were more preferred than the consonant major and minor triads. This proposes an ostensible paradox: Consonance and preference or pleasantness are often seen as indisputably overlapping or even being completely *synonymous* in terms of harmony perception (see e.g., Bidelman & Krishnan, 2011; Cousineau et al., 2012; Tramo, Cariani, Delgutte, & Braida, 2001; Tymoczko, 2011). Parncutt (1989), however, aptly reminds that "relatively consonant sounds are not necessarily preferred to relatively dissonant sounds. If this were the case, single tones would always be preferred to chords" (p. 57). He proposes that the relationship between dissonance (complexity) and preference usually takes the form of an inverted-U curve: "for relatively low degrees of dissonance, preference increases with increasing dissonance, while for relatively high degrees, preference decreases with increasing dissonance" (p. 57).

While the inverted-U hypothesis (e.g., Berlyne, 1971) offers one possible explanation for why mild dissonance is preferred over consonance in single chord perception, it does not seem to be all-encompassing. For example, it cannot account for the fact that according to the data of Lahdelma and Eerola (2016), the dominant seventh chord (major–minor seventh) was less preferred than the major and minor triads, which according to the inverted-U hypothesis as such should be the other way around; the dominant seventh being somewhere in between the extremes of consonance and dissonance when considering a large number of possible chord sonorities (cf. Huron, 1994). Moreover, on an empirical note, Orr and Ohlsson (2005) did not find evidence for an inverted-U relation for experts in their experiment when testing the relationship between liking and complexity in musical improvisations.

Inspecting the phenomenon from a different angle, it is striking how in Huron's (1994) *aggregate dyadic consonance* calculations (the sum of the consonances of all interval classes within a chord) the most consonant pitch set for tetrads (out of all possible four-pitch combinations) is the minor seventh chord, the major seventh chord being the third most consonant. Intriguingly, with regard to tetrachords, the highest amount of aggregate dyadic consonance is parallel with the evaluations for highest subjective preference in the data of Lahdelma and Eerola (2016). Huron (1994), however, reminds that "in the case of these three- and four-note sets, it is important to recognize that the consonance measures do not reflect the consonance of the complete set of concurrently sounding tones (such as the consonance of 'a major triad')" (p. 301). Despite this important caveat, the analogy between high aggregate dyadic consonance and preference in single chords is striking.

As pitch class sets comprising five and six pitches yield the most aggregate dyadic consonance in single chords (Huron, 1994), the aim of the current experiment is to broaden the chord palette of Lahdelma and Eerola (2016) to encompass not only triads and tetrachords but also penta- and hexachords containing most aggregate dyadic consonance to empirically test how these are perceived compared with one another and whether there indeed is the possibility that high aggregate dyadic consonance values predict preference in single chord perception.

In addition, the current experiment's aim is to test whether the found differences in the perception of triadic inversions in the data of Lahdelma and Eerola (2016) hold up with randomized chord roots. In their data, with the major triad, the tendency was that the applied dimensions of *valence*, *tension*, and *energy* all exhibited a pattern of increasing ratings from root through first inversion to second inversion, on both applied timbres (piano and strings). A similar pattern also occurred for the dimensions of *interest or expectancy*, *happiness or joy*, and *liking or preference*. However, in their experiment, the chords were played only in a single octave (C4) and exclusively with C roots. Hence, the results could be due to register differences between the

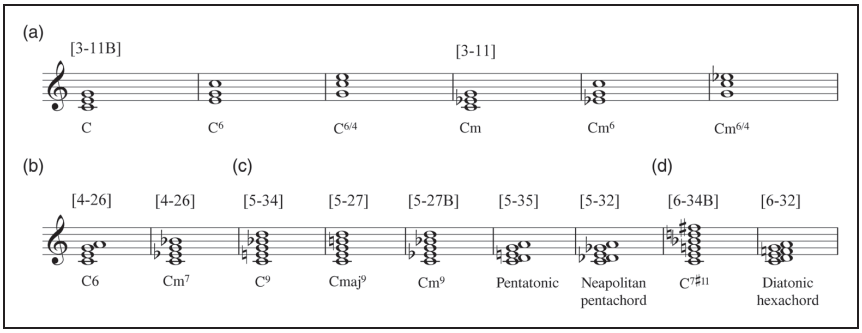

Figure 1. The chord stimuli. The chords are notated here with C roots; Forte pitch-class set names can be seen above each individual chord type in brackets. Additional descriptive names taken from Solomon (2005). (a) Triads with inversions, (b) Tetrachords, (c) Pentachords and (d) Hexachords.

inversions (e.g., the major triad's second inversion being higher in register than the root position and the first inversion), as pitch height reportedly affects actual music perception (e.g., Ilie & Thompson, 2006; Jaquet, Danuser, & Gomez, 2014). Thus, we feel that with regard to the triadic inversions, the randomization of chord roots across two octaves can tell us more about the role of register in accounting for the results of Lahdelma and Eerola (2016).

Experiment

In the current experiment, we asked participants to rate single chords (see Figure 1) isolated from all musical context (major and minor triads with inversions, selected tetra-, penta-, and hexachords in root positions) using five scales measuring separate emotional and perceptual qualities.

The first three bipolar dimensions of the five scales were adopted from Schimmack and Grob (2000). Their three-dimensional model of affect attempts to capture the core affects using the three bipolar dimensions of *valence* (intrinsic attractiveness or aversiveness), *energy arousal*, and *tension arousal*. These dimensions have been applied in studies using actual music as stimuli (e.g., Ilie & Thompson, 2006), effectively separating the effects of register on perception, as well as in an experiment conducted directly on single chord perception (Lahdelma & Eerola, 2016). The fourth applied dimension was *consonance* (used in studies by e.g., Bidelman & Krishnan, 2011; Roberts, 1986) in order to capture the participants' subjective perception of consonance and dissonance in a given chord. The fifth dimension measured the participants' subjective *preference* for each chord. These last two dimensions were chosen in order to investigate the amount of intersection between perceived consonance and preference with regard to single chord perception.

Method

Participants. The participants for the study were recruited through the Internet with the aim of drawing the attention of both musicians and nonmusicians in order to have a substantial, heterogeneous, and international participant pool (see e.g., Honing & Ladinig, 2008 and Honing & Reips, 2008 for a review of the benefits of this strategy). The experiment was

advertised in the social media (Twitter, Facebook, and LinkedIn) and on the mailing lists of different universities, music institutions, and music research communities around the world. As an incentive, three €30 gift cards to *Amazon* were drawn between all participants who left their e-mail addresses for this purpose after taking the experiment. The total amount of participants was 434, out of which 418 were considered valid for further statistical analysis; 12 participants were removed due to technical problems evident on the basis of the interface's result database (and in most cases corroborated by reports that certain chords did not play because of internet connection problems), and 4 participants were annulled as their answers were obviously malicious in nature (i.e., no chord evaluations done or evidently random clicking in a minimum amount of time spent on the experiment website). Out of the remaining 418 participants, 8 extreme outliers were removed (described in more detail in the Results), making the final number of valid cases 410.

In total, 42 different nationalities were represented in the final participant pool (continental breakdown: 61.2% Europe, 30.5% Americas, and 8.3% others). The biggest nationality groups represented were Finland (33.9%), the USA (21.2%), and Great Britain (9.8%). The participants were aged 15 to 87 years (mean = 30.7, $SD = 13.4$, 50% males). The participants' musical sophistication was measured with the *Ollen Musical Sophistication Index* (Ollen, 2006), a 10-item questionnaire yielding a score for each participants' musical sophistication between 0 and 999 (mean = 545, $SD = 336.9$), the score of 500 being the threshold between a respondent being *more musically sophisticated* and *less musically sophisticated* (see Marcs Auditory Laboratories, http://marcs-survey.uws.edu.au/OMSI/omsi.php).

Stimuli. The chord material (Figure 1) consisted of major and minor triads (played in their root positions and in their first and second inversions, respectively), tetrachords (major sixth and minor seventh), pentachords (dominant ninth, minor ninth, major ninth, pentatonic, and Neapolitan pentachord [as referred to in Solomon, 2005]), and hexachords (dominant seventh sharp eleventh and diatonic hexachord). Only the triad chords were played with inversions in order to further investigate the results of Lahdelma and Eerola (2016), all other chords were played exclusively in their root positions. All chords were played in close position. The tetrachords, pentachords, and hexachords were selected on the basis of Huron's (1994) table for chords containing most aggregate dyadic consonance.

As *familiarity* is an important component in chord perception (see e.g., Parncutt & Hair, 2011), we decided to include highly consonant chords (selected from a list by Tymoczko, 2011, p. 63) that are more familiar from actual musical context when compared with some of the rarer chord sonorities containing high aggregate dyadic consonance in order to see how this possibly affects the chord evaluations. The major sixth and the minor seventh represent the same pitch-class set as they contain the same pitches in different orderings; we decided to include both chords in order to investigate if there is any difference in how they are perceived depending on the chord's root.

All selected chords were transposed with a randomization across two octaves (± 5 semitones around C4 and C5, the possible chord roots being all equally likely to occur within this range). Thus, the stimuli consisted of 15 chords (Figure 1) performed with piano timbre across two octaves, making the total sum of chords for each participant 30. All chords were exactly 4.8 seconds in length and played in equal temperament. The chords were generated with *Ableton Live 9* (a commercial music sequencer software), using the *Synthogy Ivory Grand Pianos II* plug-in. The applied sound font was *Steinway D Concert Grand* with a touch of ambience reverb added to the chord samples to make them sound more natural. The attack, articulation, and reverb values of the chords were kept as neutral as

possible to keep the participants' attention exclusively on the actual chords. The stimuli can be found online at http://dx.doi.org/10.7910/DVN/GE5PPL

Procedure. The web-based chord evaluation application was programmed with JavaScript. The application was made specifically for the purpose of the current experiment and was accessible online between May 15, 2015 and June 12, 2015. It was programmed to gather the participants' demographic background information (gender, nationality, age), musical preference (*Short Test Of Music Preferences*; Rentfrow & Gosling, 2003), musical sophistication (*Ollen Musical Sophistication Index*; Ollen, 2006), and the type of audio device used to take the experiment.

The participants received the following instructions:

> In the experiment you will be asked to rate 30 chords on 5 dimensions, and to provide some background information concerning your musical education. You can listen to each chord as many times as you like before evaluating it. Each chord should be evaluated as a separate entity, regardless of preceding or sequential chords.

The participants were asked to rate each chord on the presented 5-item scale (Appendix). The five dimensions were rated on a Likert scale ranging from 1 to 7. With *valence*, the bipolar extremes were 1 = *negative* and 7 = *positive*. With *tension*, the extremes were 1 = *relaxed* and 7 = *tense*, and with *energy*, the extremes were 1 = *low* and 7 = *high*. With *consonance*, the extremes were 1 = *rough* and 7 = *smooth*, these two poles having been used extensively in research literature (e.g., Bregman, 1994; Parncutt & Hair, 2011; van de Geer, Levelt, & Plomp, 1962). For *preference*, the applied poles were 1 = *low* and 7 = *high*. The participants were given the chance to listen each chord as many times as they wished. The ordering of the chords, the chords' roots (across two octaves), as well as the ordering of the five dimensions were randomized for each participant.

Results

All extreme outliers (over ± 3.0 *SD*'s in dimension aggregations, 8 sets of answers altogether) were removed from the participant pool ($N = 418$), making the final number of valid cases 410. The rating scales' internal consistency was measured with Cronbach's alpha (range .80 – .87, see Table 1 for details). Correlations between the five variables were calculated (Table 1). The strongest correlations were found between the dimensions of *tension* and *consonance* (−.97), *tension* and *preference* (−.79), and between *tension* and *energy* (.78).

Table 1. Correlations Between the Rating Scales Across Chords and Register.

	Valence	Tension	Energy	Preference	Consistency
Valence					.799
Tension	−.778**				.810
Energy	−.273	.782**			.831
Preference	.631*	−.786**	−.672**		.868
Consonance	.715***	−.965**	−.724**	.715**	.844

Note. $df = 20$. Consistency refers to Cronbach's alphas.
*$p < .01$. **$p < .001$.

While there is certainly overlap between the dimensions of *valence*, *consonance*, and *preference*, this overlap is not complete (cf. the virtually complete negative correlation between *tension* and *consonance*) and shows that perceived consonance does not automatically result in more perceived valence and preference in single chord perception.

The Effect of Musical Factors on the Chord Evaluations

To estimate whether the ratings across the chords and register exhibited any differences, a two-way repeated-measures analysis of variance was carried out for all five dimensions with the Chord Type and Register (Low and High) as the two within-subject factors. Chord Type consisted of the 11 main categories of chords in which the triadic inversions were collapsed into the main types of triad chords.

Chord Type and Register. As displayed in Table 2, all scales display significant main effects of Chord Type and Register. Out of these two factors, Chord Type is typically larger, with effect sizes ranging from 0.07 to 0.37, whereas Register exhibits considerably lower effect sizes (0.001–0.04). In all cases, except for *energy*, there was also a weak interaction between the factors. The summary of the analysis of variance (Table 2) reveals that for *valence*, *tension*, and *consonance*, the differences in ratings across Chord Type were strikingly large (i.e., effect sizes above .25, which display generalized eta squared values, η^2_G, at the Chord Type column's right side). The effect sizes across Register (the Register column's right side) were considerably smaller, the two largest being on the dimensions of *tension* (.04) and *energy* (.03). The effect size for *valence* was conspicuously small, and these findings are in line with Parncutt (2014b) who proposes that pitch height in music is normally associated with *arousal*, not valence. Parncutt also suggests that music with a high average pitch tends to contain more energy than music with a low average pitch; this seems to hold true also for single chord perception. Ilie and Thompson (2006) also found tension to grow with pitch height in an empirical setting using actual musical excerpts as stimuli; again, this same effect is present in single chord perception as well (Figure 2).

The main effects of Chord Type across the dimensions provide further interesting results. When we look at the effects of Chord Type (aggregated over register), the perceived *valence* was highest for the major triad with a mean of 5.56 ($SD = 1.27$) and lowest for the Neapolitan pentachord with a mean of 2.62 ($SD = 1.26$). Perceived *tension* was highest for the Neapolitan

Table 2. Two-Way ANOVA for All Dimensions.

	Chord Type		Register		Chord Type × Register	
	F	η^2_G	*F*	η^2_G	*F*	η^2_G
Valence	348.55***	.29	9.20**	.001	4.44***	.003
Tension	433.24***	.33	228.58***	.04	3.19***	.002
Energy	78.87***	.08	155.91***	.03	1.28	.0009
Consonance	538.61***	.37	77.50***	.01	1.96*	.001
Preference	65.08***	.07	86.51***	.01	6.09***	.004

Note. $df = 10,4090$ for chord, $df = 1,409$ for register, and $df = 10,4090$ for Chord × Register. All *p* values corrected for sphericity with Greenhouse-Geisser procedure and for multiple testing with Bonferroni adjustment.
*$p < .05$. ** $p < .01$. *** $p < .001$ (two-tailed).

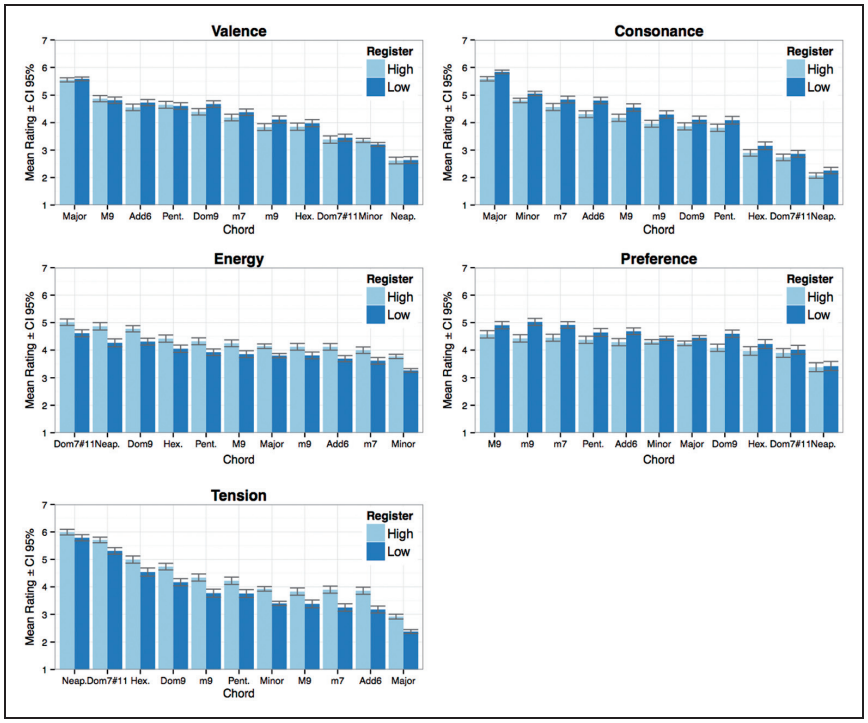

Figure 2. Mean ratings of the five dimensions across Chord Type and Register.

pentachord with a mean of 5.89 ($SD = 1.11$), followed by the dominant seventh sharp eleventh chord with a mean of 5.51 ($SD = 1.15$). The lowest mean rating on the dimension of *tension* was for the major triad's mean of 2.65 ($SD = 1.46$). Perceived *energy* was highest for the dominant seventh sharp eleventh chord with a mean of 4.81 ($SD = 1.28$), followed by the Neapolitan pentachord's mean of 4.56 ($SD = 1.47$), and the dominant ninth's mean of 4.54 ($SD = 1.25$). The lowest mean rating on the dimension of *energy* was for the minor triad with a mean of 3.52 ($SD = 1.34$). The perceived *consonance* mean rating was highest for the major triad with a mean of 5.71 ($SD = 1.31$), the lowest for the Neapolitan pentachord's mean of 2.16 ($SD = 1.13$). On a side note, it is worth noting how the added sixth chord ($M = 4.49$, $SD = 1.31$) was perceived as less consonant than the minor seventh chord ($M = 4.68$, $SD = 1.30$), even though the chords represent the same pitch class set. The highest rating on the dimension *preference* was for the major ninth chord with a mean of 4.74 ($SD = 1.39$), followed closely by the minor ninth's mean of 4.72 ($SD = 1.39$), and the minor seventh's mean of 4.68 ($SD = 1.30$). The lowest mean rating on the dimension of *preference* was for the Neapolitan pentachord with a mean of 3.40 ($SD = 1.65$), followed by the dominant seventh sharp eleventh chord's mean of 3.95 ($SD = 1.65$).

We also explored the influence of additional variables such as diatonicity (the proportion of tones belonging to diatonic scales within each chord) and chord ambitus (difference

Table 3. Two-Way ANOVA Across the Triadic Inversions for All Dimensions.

	Inversion		Chord Type		Interaction	
	F	η^2_G	*F*	η^2_G	*F*	η^2_G
Valence	5.99*	0.00	998.3**	0.53	3.38*	0.00
Tension	101.5**	0.04	430.1**	0.16	0.16	0.00
Energy	56.6**	0.03	79.5**	0.04	4.0*	0.00
Consonance	36.9**	0.01	325.7**	0.11	0.7	0.00
Preference	1.3	0.00	0.1	0.00	1.1	0.00

Note. $df = 1{,}409$ for chord, $df = 2{,}818$ for inversion, and $df = 2{,}818$ for Chord × Inversion. All *p* values corrected for sphericity with Greenhouse-Geisser procedure and for multiple testing with Bonferroni adjustment.
*$p < .05$. **$p < .001$ (two-tailed).

between highest and lowest tone in semitones) to ANOVA analyses as within-subject covariates, but both of these variables failed to make an impact on the results.

Triadic inversions. As can be seen from Table 3, the perception of triadic inversions is mostly in line with the results of Lahdelma and Eerola (2016): *Energy* and *tension* exhibit significant main effects with the ratings growing from root through first inversion to second inversion in both major and minor triads, and the scale of *preference* does not exhibit a significant main effect with regard to inversions. The current study's added scale of *consonance or dissonance* exhibits a significant main effect with an opposing pattern when compared with the scales of *tension* and *energy*: In both major and minor triads, perceived consonance decreases from root through first inversion to second inversion (Figure 3). With regard to the major triad, the least amount of perceived consonance in the chords' second inversion is notably in line with musical convention (see e.g., Randel, 2003); intriguingly, however, this pattern of perception was not influenced by musical sophistication. Strikingly, both musicians and nonmusicians distinguished between the triadic inversions on the dimensions of energy, tension, and consonance or dissonance similarly. To our knowledge, the current experiment is the first one to empirically demonstrate this trend.

The only notable difference between the current data and the results of Lahdelma and Eerola (2016) is on the scale of *valence*. While exhibiting a statistically significant main effect, this significance is considerably smaller in the current data and showcases a different pattern. The randomization of roots seems to have dissolved virtually any perceived difference between the major triad's inversions, and the minor triad's first inversion was perceived as containing the most amount of positive *valence* (Figure 3); in the data of Lahdelma and Eerola (2016), the difference between the minor triad's first and second inversions with regard to valence was negligible. However, the current finding could be explained with the fact that the minor triad's first inversion has a major third above the bass and might hence sound somewhat "major." Curiously, Hutchinson and Knopoff (1979) suggest that the minor triad's first inversion is actually the most consonant of the chords' inversions; paradoxically this was not corroborated by the current empirical data (despite the most perceived *valence* in this particular inversion), as the minor triad's root position was perceived as containing more consonance than its first inversion.

In sum, the randomized chord roots of the triads might provide a slightly more accurate picture of the perceived differences between the triadic inversions, but the overall tendency of the current results is quite similar to the findings of Lahdelma and

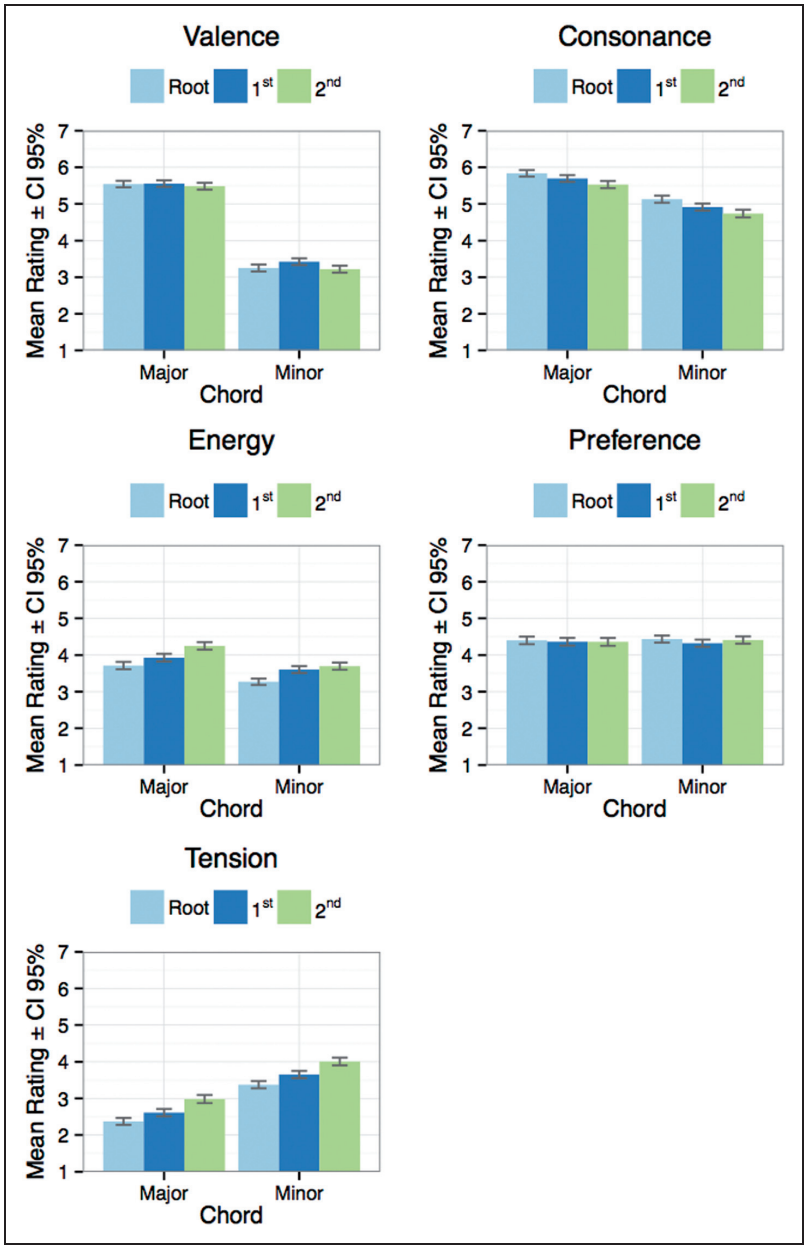

Figure 3. Mean ratings of the triadic inversions across all dimensions.

Eerola (2016) who did not randomize chord roots in their study and played the triads exclusively with C-roots.

The Effect of Background Factors on the Chord Evaluations

Past studies indicate that gender (e.g., Costa et al., 2000; Lahdelma & Eerola, 2016) and musical expertise (e.g., Lahdelma & Eerola, 2016; McLachlan, Marco, Light, & Wilson, 2013) may affect vertical harmony perception. Moreover, it has been suggested that familiarity affects the perception of chords (e.g., McLachlan et al., 2013; Parncutt & Hair, 2011) and the perception of consonance or dissonance in general (e.g., Cazden, 1972; Heyduk, 1975).

In the current study, musical expertise was assessed with the *Ollen Musical Sophistication Index* (Ollen, 2006); music preferences were inferred from the ratings of 13 genres that were recoded into four meta-genres suggested by Rentfrow and Gosling (2003) according to hierarchical cluster analysis clustering the participants according to the similarity of their music preferences into four clusters. Each participant belonged to one of these clusters, labeled as *Reflective or Complex* ($n = 215$), *Intense or Rebellious* ($n = 86$), *Upbeat or Conventional* ($n = 76$), or *Energetic or Rhythmic* ($n = 33$). Separate mixed ANOVAs were carried out with emotion ratings across the three between-subjects factors (Gender, Musical Expertise, and Music Preferences) reported in Table 4.

Most of the ratings scales did not yield significant main effects; we will now briefly outline the ones that actually portrayed differences. For *valence* ratings, Gender, Musical Expertise, and Music Preferences yielded significant differences; males rated the chords as more positively valenced ($M = 4.30$, $SD = 1.53$) than females ($M = 4.15$, $SD = 1.60$), musicians more positively ($M = 4.36$, $SD = 1.57$) than nonmusicians ($M = 4.07$, $SD = 1.54$), and those labeled as preferring music that is "reflective and complex" also had higher ratings of valence ($M = 4.33$, $SD = 1.57$) than the other three music preference groups ($M = 4.11$, $SD = 1.52$). For ratings of *energy*, only Music Preferences showed significant differences (those classified as listening to Upbeat or Conventional music, $M = 4.09$, $SD = 1.39$, whereas listeners of Intense or Rebellious music rated the chords lower on energy, $M = 3.89$, $SD = 1.33$). With respect to *tension*, none of the background variables contributed to the chord ratings. *Consonance*, on the other hand, exhibited differences according to Gender and Musical Expertise, where males ($M = 4.42$, $SD = 1.66$) displayed higher ratings than females ($M = 4.32$, $SD = 1.71$) and those listening to Reflective or Complex music displayed higher ratings ($M = 4.44$, $SD = 1.73$) than other listeners ($M = 4.24$, $SD = 1.62$). Finally, *preference*

Table 4. ANOVA Summary for All Ratings Across the Main Background Variables.

	Gender		Musical expertise		Music preferences	
	F	η^2_G	F	η^2_G	F	η^2_G
Valence	7.21*	0.00	12.86*	0.01	3.84*	0.01
Energy	0.05	0.00	2.42	0.00	3.22*	0.00
Tension	0.85	0.00	0.18	0.00	0.52	0.00
Consonance	5.6*	0.00	5.95*	0.01	0.91	0.00
Preference	7.3*	0.01	8.64*	0.01	3.6*	0.01

*$p < .05$.

indicated significant differences across the background variables, being very similar to the pattern exhibited by *valence* (males, musicians, and those preferring reflective and complex music showing higher ratings of preference for all chords). It is important to note here that few of the scales displayed interactions between background variables and chords. The exceptions were *energy*, where Musical Expertise displayed an interaction with chord types, $F(10, 3940) = 3.74$, $p < .001$, and *tension*, where Musical Expertise, $F(10, 3940) = 6.37$, $p < .001$, and Gender, $F = 1.83$, $p < .001$, interacted with chord types. Also *consonance* interacted with Musical Expertise and chords ($F = 3.51$, $p < .001$), as well as *preference*, where Music Preferences created an interaction with the chord types ($F = 2.28$, $p < .001$).

To summarize, these results suggest that those with higher musical expertise perceived the chords as more positive in valence, more consonant, and also preferred the chords more. This finding is in line with the notion that familiarity in fact affects the perception of chords (McLachlan et al., 2013), as well as the perception of consonance or dissonance in general (Cazden, 1972; Heyduk, 1975). In the context of all ratings, the magnitude of variations according to background, however, is considerably small and negligible (effect sizes < .01).

Acoustic Properties of the Chords

To examine the relationship between psychoacoustic properties and perceptual evaluations of the chords, few selected features were extracted using MIR toolbox (version 1.6.1; Lartillot, Toiviainen, & Eerola, 2008) and custom MATLAB functions based on prior studies. These were (a) harmonicity (Jensen, 1999) that accounts for the regularity of the amplitude of adjoining partials, (b) roughness that captures the sensory beating of the partials in the sound using a psychoacoustic model by Vassilakis (2001), and (c) sharpness that is related to the high-frequency content of the sound (Zwicker & Fastl, 1991). Figure 4 displays the mean values across the chord types for all three features. Moreover, to formally connect the ratings to these descriptors, a linear regression was used to assess the degree of fit between the descriptors and the ratings (see Table 5).

As can be seen in Table 5, roughness and sharpness correlate statistically significantly with the dimensions of *tension*, *energy*, and *consonance*. Both roughness and sharpness correlate positively with *tension* and especially with *energy*, while negatively with *consonance*. We suggest that the lesser amount of perceived consonance in chords played in the higher register (Figure 2) could be explained with the effect of sharpness, as chords in the lower register actually have significantly more objective roughness compared with chords in the higher register (Figure 4), despite being subjectively perceived as more consonant. This finding is in line with the notion that sharpness is another form of sensory dissonance (in addition to roughness), caused by energy at high frequencies (see Aures, 1985a, 1985b).

With regard to the difference between objective roughness and subjective dissonance, the current data offer some intriguing insights. As can be seen from Figure 4, the diatonic hexachord is theoretically more rough than the dominant sharp eleventh chord, and the pentatonic chord more rough than the Neapolitan pentachord. The ordering of these chords' subjective dissonance, however, was exactly the opposite: the pentatonic chord was perceived as significantly more consonant compared with the Neapolitan pentachord and the diatonic hexachord slightly more consonant compared with the dominant sharp eleventh chord (Figure 2). This difference could be explained with Johnson-Laird, Kang, and Leong (2012) concept of *tonal dissonance*. They suggest that dissonance

> Results from a combination of sensory and tonal dissonance, where 'sensory' dissonance arises . . . in particular from roughness (i.e., the rapid beating of partials), and 'tonal'

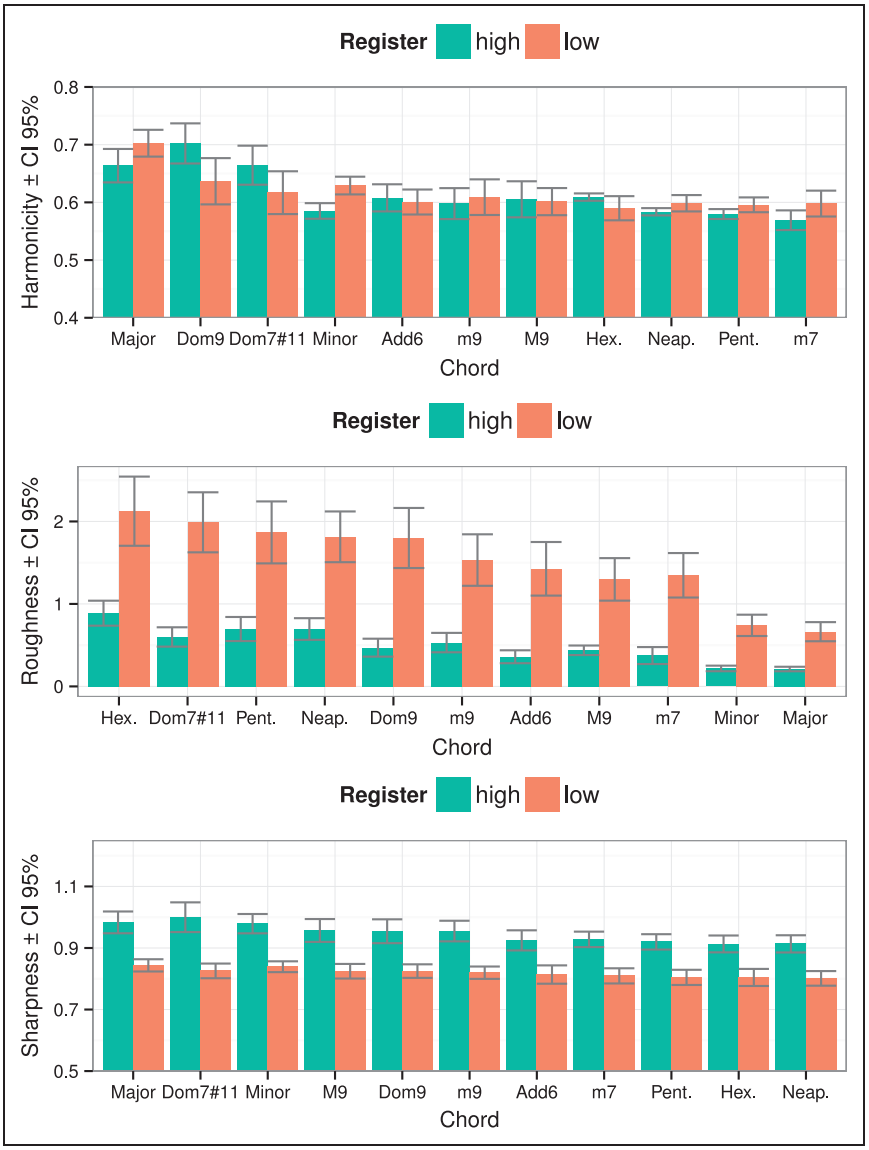

Figure 4. Harmonicity, Roughness, and Sharpness values across Chord Types and Register.

Table 5. Regression Results With Harmonicity, Roughness, and Sharpness Across the Mean Ratings for All Chords (Triadic Inversions Collapsed Into Main Chord).

	Harmonicity β	Roughness β	Sharpness β	R^2	F	p
Valence	0.341	−0.476	−0.470	0.187	1.38	0.282
Tension	−0.142	1.230**	1.257 **	0.447	4.84	0.012
Energy	0.211	1.232***	1.481 ***	0.603	9.13	0.001
Consonance	0.209	−1.267***	−1.134***	0.475	5.43	0.008
Preference	−0.050	−0.582	−0.788	0.171	1.24	0.326

Note. Normalized betas and the model fit indices are shown.
**$p < .01$. ***$p < .01$. $df = 3,18$.

> dissonance is a consequence of high-level cognitive processes that rely on a tacit knowledge of the principles of tonality. (p. 24)

They propose that tonal dissonance depends on the scales in which the chords can occur: "chords occurring in a major scale should be less dissonant than chords occurring only in a minor scale, which in turn should be less dissonant than chords occurring in neither sort of scale" (p. 24). The Neapolitan pentachord is not present in either of the scales, and it was in fact perceived as the least consonant and was the least preferred of all the presented chords in the current experiment. The second least consonant and preferred dominant sharp eleventh chord is not present in a major scale (cf. the diatonic hexachord) either, but could theoretically be constructed from the melodic minor scale's pitches in an extended tonality. The rest of the chords applied in the current experiment contain no tonal dissonance. Hence, the results clearly corroborate Johnson-Laird et al.'s (2012) theory of tonal dissonance with regard to single chord perception.

It is somewhat surprising that harmonicity did not exhibit statistically significant correlations with any of the five dimensions. As higher harmonicity is often seen as resulting in a higher amount of perceived consonance (e.g., Cousineau et al., 2012; McDermott et al., 2010), and consonance in turn being often described as a synonym for pleasantness (e.g., Bidelman & Krishnan, 2011; Bones, Hopkins, Krishnan, & Plack, 2014), the data of the current study imply that harmonicity does not automatically result in consonance and preference in the case of single isolated chords consisting of three or more pitches. Concrete examples of this phenomenon in the current data are the chords of the dominant ninth and the dominant sharp eleventh: Both chords have strikingly high harmonicity values (Figure 4) but were nonetheless rated quite low on the dimensions of *consonance* and *preference* (Figure 2). The pentatonic chord in turn has a low amount of harmonicity but was rated relatively high for *preference*. The chord with the lowest amount of harmonicity, the minor seventh, was in fact perceived as the third most consonant and also the third most preferred among the presented chords. The obtained results might also be influenced by the piano timbre that was used in the current experiment. We will return to these questions in the Discussion part.

As harmonicity, roughness, and sharpness by themselves did not correlate statistically significantly with the dimension of *preference*, we will next outline the possibility of how aggregate dyadic consonance (Huron, 1994) might affect perceived preference in single chords.

Aggregate Dyadic Consonance

Aggregate dyadic consonance and roughness seem to be related to preference in a curvilinear fashion. There is no linear correlation between the means of the chords in terms of preference and aggregate dyadic consonance ($r = -.16$, $p = .68$) or roughness ($r = -.24$, $p = .54$), but a

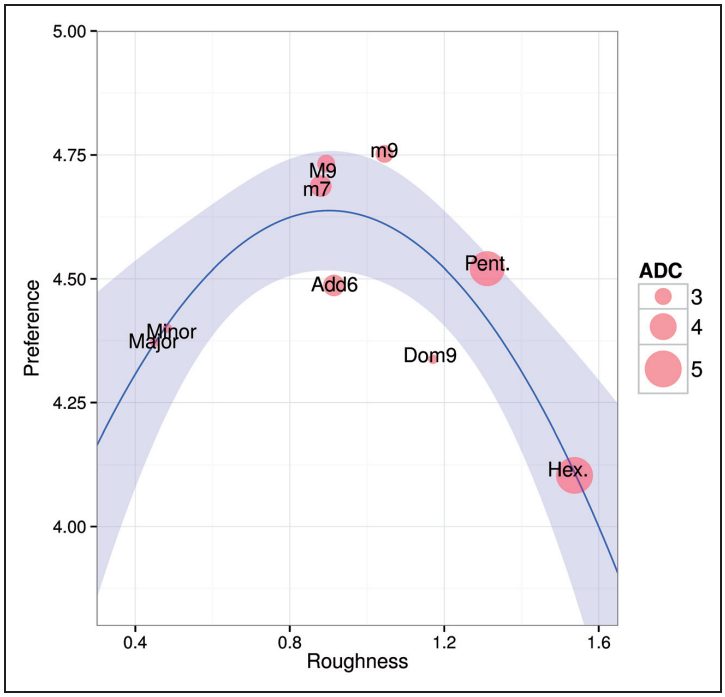

Figure 5. Preference, Roughness, and Aggregate Dyadic Consonance values across Chord Types, excluding chords containing tonal dissonance.

second-order polynominal fits the relation better (see Figure 5), especially for roughness ($R^{2adj} = .58$, $p < .05$). In other words, combining the aspects of roughness and aggregate dyadic consonance could explain why mildly dissonant chords are most preferred. The chords of the dominant sharp eleventh and the Neapolitan pentachord are omitted from this model, as they contain tonal dissonance (Johnson-Laird et al., 2012).

As can be seen from Figure 5, chords that contain a medium amount of roughness (minor ninth, minor ninth, minor seventh, added sixth, and dominant ninth) are not equally highly preferred as would be predicted by the inverted-U hypothesis. The minor ninth, the major ninth, and the minor seventh chords are more preferred than the other semi-rough chords, possibly because they contain high aggregate dyadic consonance. While the added sixth chord contains the same amount of aggregate dyadic consonance as the minor seventh chord, it however contains slightly more roughness; the major second interval present in the chord clearly has a negative impact on its preference, possibly due to enculturation (cf. Krantz et al., 2004). As for the pentatonic and hexatonic chords, these chords also contain high amounts of aggregate dyadic consonance, but the overall roughness of these chords seems to "overrule" their preference, especially in the hexatonic chord's case. The preference ratings dramatically drop between the pentatonic and the hexatonic chords: It could be argued that there is a critical threshold of roughness in single chord perception which cannot be exceeded in order for the chord to gain high preference ratings.

Curiously, however, the high amount of roughness and subjective dissonance in the pentatonic chord should theoretically predict a much higher aversion—its high aggregate dyadic consonance

might explain why the chord is relatively preferred nonetheless. In other words, a moderately high amount of roughness does not automatically result in declined preference in single chord perception. In the hexatonic chord's case, the overall roughness of the chord seems to cross that critical threshold for roughness: this particular chord is the roughest of all the presented chords, and hence not preferred despite its theoretically high aggregate dyadic consonance. Thus, interestingly a combination of the U-theory with aggregate dyadic consonance seems to most effectively predict preference in single chord perception: the most preferred chords contain a moderate amount of aggregate dyadic consonance. It is important to keep in mind, however, that the current model has only nine data points; further research is needed to shed light on the role of aggregate dyadic consonance on the preference of single chords.

Discussion

This study aimed to investigate how listeners perceive single chords across a 5-item scale of dimensions consisting of *valence*, *tension*, *energy*, *consonance*, and *preference*. The results suggest that mildly dissonant chords in terms of both *musical* (see e.g., Révész, 1954) and *sensory* consonance or dissonance were actually more preferred than maximally consonant chords among a large and heterogeneous pool of participants, across both expert and inexpert listeners.

We outlined theoretical explanations to account for the preference of mild dissonance in single chord perception. These include *aggregate dyadic consonance* (Huron, 1994), the inverted-U hypothesis (e.g., Berlyne, 1971), as well as the role of psychoacoustic phenomena in the form of harmonicity, roughness, and sharpness. We feel that the inverted-U hypothesis is not necessarily all encompassing to account for the preference of mild dissonances: Both the dominant seventh chord in the data of Lahdelma and Eerola (2016) as well as the dominant ninth in the current study were rated low for preference even though these chords are representing middle ground in terms of complexity when considering a wide range of sonorities.

The overall results suggest that the background factors of gender, musical sophistication, and musical preferences affected single chord evaluations to some extent—musicians interestingly objecting less to dissonance than nonmusicians. The overall magnitude of variations according to background was, however, quite small. Nonetheless, the findings are in line with propositions that familiarity affects chord perception (McLachlan et al., 2013) as well as the evaluation of consonance or dissonance (Cazden, 1972; Heyduk, 1975). On the other hand, it is intriguing how familiarity does not seem to predict preference in the dominant ninth chord's case: It is the only pentad present in major–minor tonality and should thus be more familiar than the other, possibly more exotic five-pitch sonorities used in the current experiment. Despite its familiarity, the dominant ninth was the least preferred pentad after the Neapolitan pentachord. This is somewhat surprising taking the high amount of harmonicity and only the moderate amount of roughness present in the chord. We surmise that the low preference for the dominant seventh chord (Lahdelma & Eerola, 2016) and the current study's dominant ninth chord might stem from the culturally loaded tritone interval present in these chords. The avoidance of tritone as an interval has both psychoacoustic and cultural origins (Parncutt, 1989, 2014a), and this avoidance seems to influence also the perception of chords in which it is present. The chord also contains low aggregate dyadic consonance. The low-perceived consonance and preference of the Neapolitan pentachord also suggests the role of enculturation in the form of *tonal dissonance* (Johnson-Laird et al., 2012) instead of a purely psychoacoustic explanation: This particular chord was the least preferred sonority and judged clearly as subjectively least consonant, despite not being among the objectively roughest chords

of the presented stimuli. Hence, we see that enculturation indeed affects judgments of sensory consonance or dissonance also even in single isolated chords, not just in chords within a musical context (cf. Minati et al., 2009).

Also the difference between the perceived amount of consonance in the common pitch class set of the added sixth and the minor seventh chords is intriguing; the added sixth chord was perceived as more dissonant than the minor seventh chord. We surmise that this is caused by the slightly higher amount of roughness that the added sixth chord contains when compared with the minor seventh chord. An interesting detail is that the added sixth chord was nonetheless perceived as more positive in valence than the minor seventh chord. This could imply that the added sixth is more affiliated with the major triad because of its root when compared with the minor seventh, and again suggests that enculturation affects single chord perception in addition to psychoacoustics.

The negligible role of harmonicity in the perception of single isolated chords is somewhat surprising, especially when considering the importance it has been given in previous research (e.g., Cousineau et al., 2012; McDermott et al., 2010) with regard to the question of consonance or dissonance. However, this finding is in line with Bregman (1994), who suggests that "harmonicity may not be critical for chord perception" (p. 496). Also, according to Mellinger and Mont-Reynaud (1996) the relationship between harmonicity and the perception of harmony is a complex one, and for example, perceived pleasantness is not necessarily completely tied to harmonicity.

Parncutt (2012) proposes that dissonance is in fact based on a *combination* of roughness, harmonicity, and familiarity. If we consider chord perception encompassing also *emotion* perception, Lahdelma and Eerola (2015) demonstrate a theoretical possibility of the role of harmonicity affecting the perception of complex musical emotions conveyed by single isolated chords. With the dimensions used in the current study, however, harmonicity does not offer any significant explanation to account for the results. This may have to do also with the fact that the current experiment applied only the piano timbre. According to Pierce (1999), the small departures from perfect harmonicity are important to the piano sound; in other words, harmonicity is presumably more important in nonpercussive, steady sounds than in percussive, rapidly fading sounds. The role of timbre with regard to the importance of harmonicity in single chord perception is a crucial question and should be addressed with future experiments. Also, the question of the relationship between sensory and musical consonance is a fascinating one: How does the perception of single chords change when heard in different kinds of musical contexts (cf. Bharucha & Stoeckig, 1986; Krumhansl, 1990)?

We see that the possible role of pitch relations (aggregate dyadic consonance) with regard to the perception of single isolated chords should be examined further. The role of aggregate dyadic consonance as an explanation for why the relationship between the lack of roughness and preference is not linear could be studied with a higher number of chord sonorities. Also, the crucial threshold of maximum roughness in simultaneous pitch combinations resulting in a decline of preference should be investigated.

The current results suggest that vertical harmony perception may have more to do with horizontal harmony perception with regard to single chords than has been previously thought; this finding is in line with Tramo et al. (2001) who point out that "a listener's implicit (or explicit) knowledge about harmony in the horizontal dimension bears on harmony perception in the vertical dimension" (p. 96). Furthermore, it is tantalizing to draw a parallel between these two distinct aspects of harmony when considering a historical point of view. As Parncutt (1989) points out (referring to Grout, 1960), horizontal intervals between tones existed before simultaneous tones in music: "History suggests . . . that musical intervals (octaves, fifths) between sequential tones existed long

before people started singing or playing tones simultaneously in music . . . " (p. 9). Could this evolution of harmony somehow still affect the perception of vertical sonorities? The question of how the ear parses the overall consonance of simultaneous intervals in vertical pitch combinations or whether it does so remains to be examined with future research.

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References

Aures, W. (1985a). Der sensorische Wohlklang als Funktion psychoakustischer Empfindungsgrößen (Sensory consonance as a function of psychoacoustic parameters). *Acustica*, *58*, 282–290.

Aures, W. (1985b). Ein Berechnungsverfahren für den sensorischen Wohlklang beliebiger Schallsignale (A procedure for calculating the sensory consonance of any sound). *Acustica*, *59*, 130–141.

Bakker, D. R., & Martin, F. H. (2015). Musical chords and emotion: Major and minor triads are processed for emotion. *Cognitive, Affective, & Behavioral Neuroscience*, *15*, 15–31.

Berlyne, D. E. (1971). *Aesthetics and psychobiology*. New York, NY: Appleton-Century-Crofts.

Bharucha, J. J., & Stoeckig, K. (1986). Reaction time and musical expectancy: Priming of chords. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 403–410.

Bidelman, G. M., & Krishnan, A. (2011). Brainstem correlates of behavioral and compositional preferences of musical harmony. *Neuroreport*, *22*, 212–216.

Bigand, E., & Parncutt, R. (1999). Perceiving musical tension in long chord sequences. *Psychological Research*, *62*, 237–254.

Bigand, E., Parncutt, R., & Lerdahl, J. (1996). Perception of musical tension in short chord sequences: The influence of harmonic function, sensory dissonance, horizontal motion, and musical training. *Perception & Psychophysics*, *58*, 125–141.

Bones, O., Hopkins, K., Krishnan, A., & Plack, C. (2014). Phase locked neural activity in the human brainstem predicts preference for musical consonance. *Neuropsychologia*, *58*, 23–32.

Bregman, A. S. (1994). *Auditory scene analysis: The perceptual organization of sound*. Cambridge, MA: MIT Press.

Cazden, N. (1972). The systematic references of musical consonance response. *International Review of Aesthetics and Sociology of Music*, *3*, 217–245.

Cook, N. D. (1999). Explaining harmony: The roles of interval dissonance and chordal tension. *Annals of the New York Academy of Science*, *930*, 382–385.

Costa, M., Bitti, P., & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music*, *28*, 4–22.

Cousineau, M., McDermott, J. H., & Peretz, I. (2012). The basis of musical consonance as revealed by congenital amusia. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 19858–19863.

Crowder, R. (1985). Perception of the major/minor distinction: III. Hedonic, musical, and affective discriminations. *Bulletin of the Psychonomic Society*, *23*, 314–316.

Gabrielsson, A., & Lindström, E. (2010). The role of structure in the musical expression of emotions. In P. Juslin, & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 393–414). Oxford, England: Oxford University Press.

van de Geer, J. P., Levelt, W. J. M., & Plomp, R. (1962). The connotation of musical consonance. *Acta Psychologica*, *20*, 308–319.

Grout, D. J. (1960). *A history of western music*. New York, NY: W.W. Norton.

Heinlein, C. P. (1928). The affective characteristics of the major and minor modes in music. *Journal of Comparative Psychology*, *8*, 101–142.

Heyduk, R. G. (1975). Rated preference for musical compositions as it relates to complexity and exposure frequency. *Perception and Psychophysics*, *17*, 84–91.

Honing, H., & Ladinig, O. (2008). The potential of the internet for music perception research: A comment on lab-based versus web-based studies. *Empirical Musicology Review*, *3*, 4–7.

Honing, H., & Reips, U.-D. (2008). Web-based versus lab-based studies: A response to Kendall (2008). *Empirical Musicology Review*, *3*, 73–77.

Huron, D. (1994). Interval-class content in equally-tempered pitch-class sets: Common scales exhibit optimum tonal consonance. *Music Perception*, *11*, 289–305.

Hutchinson, W., & Knopoff, L. (1978). The acoustical component of Western consonance. *Interface*, *7*, 1–29.

Hutchinson, W., & Knopoff, L. (1979). The significance of the acoustic component of consonance in Western triads. *Journal of Musicological Research*, *3*, 5–22.

Ilie, G., & Thompson, W. F. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception*, *23*, 319–329.

Jaquet, L., Danuser, B., & Gomez, P. (2014). Music and felt emotions: How systematic pitch level variations affect the experience of pleasantness and arousal. *Psychology of Music*, *42*, 51–70.

Jensen, T. (1999). *Timbre Models of Musical Sounds, Rapport 99/7*. Copenhagen, Denmark: University of Copenhagen.

Johnson-Laird, P. N., Kang, O. E., & Leong, Y. C. (2012). On musical dissonance. *Music Perception*, *30*, 19–35.

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory. *Journal of the Acoustical Society of America*, *45*, 1451–1469.

Kastner, M., & Crowder, R. (1990). Perception of the major/minor distinction: IV. Emotional connotations in young children. *Music Perception*, *8*, 189–202.

Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition*, North Western University, Evanston, IL.

Krumhansl, C. (1990). *Cognitive foundation of musical pitch*. New York, NY: Oxford University Press.

Kuusi, T. (2010). Comparing non-tonal tetrachords and pentachords: Both abstract properties and chordal characteristics guide evaluations. *Journal of New Music Research*, *39*, 215–225.

Kuusi, T. (2011). Kuulijoiden adjektiiviassosiaatiot soinnuista – sointujen laatuominaisuuksia, kuulijoiden kokemuksia vai musiikkiin liittyviä emootioita? (Listener evaluations of chords – connections between chordal characteristics, adjective associations and emotions?). *Musiikki-lehti*, *2*, 63–93.

Lahdelma, I., & Eerola, T. (2015). Theoretical proposals on how vertical harmony may convey nostalgia and longing in music. *Empirical Musicology Review*, *10*, 245–263.

Lahdelma, I., & Eerola, T. (2016). Single chords convey distinct emotional qualities to both naïve and expert listeners. *Psychology of Music*, *44*, 37–54.

Lartillot, O., Toiviainen, P., & Eerola, T. (2008). A Matlab toolbox for music information retrieval. In C. Preisach, H. Burkhardt, L. Schmidt-Thieme, & R. Decker (Eds.), *Data analysis, machine learning and applications* (pp. 261–268). Berlin, Germany: Springer.

Maher, T. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *American Journal of Psychology*, *93*, 309–327.

McDermott, J., Lehr, A., & Oxenham, A. (2010). Individual differences reveal the basis of consonance. *Current Biology*, *20*, 1035–1041.

McLachlan, N., Marco, D., Light, M., & Wilson, S. (2013). Consonance and pitch. *Journal of Experimental Psychology; General*, *142*, 1142–1158.

Mellinger, D., & Mont-Reynaud, B. (1996). Scene analysis. In H. Hawkins, T. McMullin, A. Popper, & R. Fay (Eds.), *Auditory computation* (pp. 271–331). New York, NY: Springer Verlag.

Minati, L., Rosazza, C., D'Incerti, L., Pietrocini, E., Valentini, L., Scaioli, V., . . . Bruzzone, M. G. (2009). Functional MRI/Event-related potential study of sensory consonance and dissonance in musicians and nonmusicians. *NeuroReport*, *20*, 87–92.

Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing*, *10*, 113–131.

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical sophistication using expert ratings* (PhD dissertation). Ohio State University, OH. Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=osu1161705351

Orr, M. G., & Ohlsson, S. (2005). Relationship between complexity and liking as a function of expertise. *Music Perception*, *22*, 583–611.

Pallesen, K., Brattico, E., Bailey, C., Korvenoja, A., Koivisto, J., Gjedde, A., . . . Carlson, S. (2005). Emotion processing of major, minor, and dissonant chords: A functional magnetic resonance imaging study. *Annals of the New York Academy of Sciences*, *1060*, 450–453.

Parncutt, R. (1989). *Harmony: A psychoacoustical approach*. Berlin, Germany: Springer-Verlag.

Parncutt, R. (2012). Major-minor tonality, Schenkerian prolongation, and emotion: A commentary on Huron and Davis (2012). *Empirical Music Review*, *7*, 118–137.

Parncutt, R. (2014a). Roughness and beats. In W. F. Thompson (Ed.), *Music in the social and behavioral sciences: An encyclopedia* (pp. 970–972). Los Angeles, CA: Sage.

Parncutt, R. (2014b). The emotional connotations of major versus minor tonality: One or more origins? *Musicae Scientiae*, *18*, 324–353.

Parncutt, R., & Hair, G. (2011). Consonance and dissonance in theory and psychology: Disentangling dissonant dichotomies. *Journal of Interdisciplinary Music Studies*, *5*, 119–166.

Pierce, J. (1999). The nature of musical sound. In D. Deutsch (Ed.), *The psychology of music* (pp. 1–23). San Diego, CA: Academic Press.

Plantinga, J., & Trehub, S. E. (2014). Revisiting the innate preference for consonance. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 40–49.

Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *Journal of the Acoustical Society of America*, *38*, 548–560.

Randel, D. M. (2003). *The Harvard dictionary of music*. Cambridge, MA: Belknap Press of Harvard University Press.

Rentfrow, P. J., & Gosling, S. D. (2003). The do re mi's of everyday life: The structure and personality correlates of music preferences. *Journal of Personality and Social Psychology*, *84*, 1236–1256.

Révész, G. (1954). *Introduction to the psychology of music* (G. I. C. De Courcy, Trans.). Norman: University of Oklahoma Press.

Roberts, L. (1986). Consonance judgments of musical chords by musicians and untrained listeners. *Acustica*, *62*, 163–171.

Schimmack, U., & Grob, A. (2000). Dimensional models of core affect: A quantitative comparison by means of structural equation modeling. *European Journal of Personality*, *14*, 325–345.

Sloboda, J. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music*, *19*, 110–120.

Solomon, L. (2005). The table of pitch class sets. Retrieved from http://solomonsmusic.net/pcsets.htm

Terhardt, E. (1984). The concept of musical consonance: A link between music and psychoacoustics. *Music Perception*, *1*, 276–295.

Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological foundations for the theory of harmony in Western tonal music. *Annals of the New York Academy of Sciences*, *930*, 92–116.

Tymoczko, D. (2011). *A geometry of music: Harmony and counterpoint in the extended common practice*. Oxford, England: Oxford University Press.
Vassilakis, P. N. (2001). *Perceptual and physical properties of amplitude fluctuation and their musical significance* (Unpublished doctoral dissertation). University of California, Los Angeles.
Webster, G. D., & Weir, C. G. (2005). Emotional responses to music: Interactive effects of mode, texture, and tempo. *Motivation and Emotion*, *29*, 19–39.
Zentner, M. R., & Kagan, J. (1998). Infants' perception of consonance and dissonance in music. *Infant Behavior & Development*, *21*, 483–492.
Zwicker, E., & Fastl, H. (1990). *Psychoacoustics: Facts and Models*. Berlin, Germany: Springer-Verlag.
Zwicker, E., & Zwicker, U. T. (1991). Audio engineering and psychoacoustics: Matching signals to the final receiver, the human auditory system. *Journal of the Audio Engineering Society*, *39*, 115–126.

Author Biographies

Imre Lahdelma is a doctoral student in musicology at the University of Jyväskylä, Finland. His multidisciplinary research focuses on vertical harmony perception in terms of both psychoacoustic qualities and emotional connotations. His articles have been published by for example *Psychology of Music and Empirical Musicology Review*. In 2015–2016 Lahdelma held a Fulbright Pre-Doctoral Fellowship (University of Washington, USA).

Tuomas Eerola received his MA and Ph. D degrees from the University of Jyväskylä, Finland, in 1997 and 2003. He is a Professor of Music Cognition at the Durham University, UK. His research interest lies within the field of music cognition and music psychology, including musical similarity, melodic expectations, perception of rhythm and timbre, and induction and perception of emotions. He is on the editorial boards of *Psychology of Music*, and *Frontiers in Digital Humanities* and is consulting editor for *Musicae Scientiae* and member of the European Cognitive Sciences of Music (ESCOM) and the Society for Education, Music and Psychology Research (SEMPRE).

Appendix

Definitions of Each Dimension on the 5-Item Scale

This is how the scales were defined and explained to the participants in the experiment.

(1) Valence. Is the chord conveying positive or negative emotions?
(2) Tension. How tense do you think the chord is? Is it calm and relaxed or tense and agitated?
(3) Energy. Do you think the chord is strong and energetic, or weak and feeble?
(4) Consonance. How smooth do you think the chord is?
(5) Preference. How much did you like the chord? Note that this is a purely subjective question: for example, you may like a chord no matter how negative or harsh it sounds.