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Introduction

Many studies have addressed the role of different musical factors in creating emotional meaning in music such as tempo, mode, articulation (e.g., Gagnon & Peretz, 2003; Webster & Weir, 2005; Juslin & Sloboda, 2010; Gabrielsson & Lindström, 2010), but the role of vertical harmony has been rather neglected in such studies. According to Gabrielsson and Lindström (2010, p. 393) "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". 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., Meyer, 1956; Cooke, 1959) without empirical support. There have been some empirical attempts to investigate the emotional qualities conveyed by vertical harmony, but such studies are either focusing on harmonic intervals (e.g., Maher, 1980; Costa et al., 2000; Krantz et al., 2004; Oelmann & Laeng, 2009) or on the major/minor triad distinction (e.g., Heinlein, 1928; Crowder, 1985; 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). Also Kuusi (2009, 2011) 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 et al., 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 (2010, 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 refer 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), also 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 & Weir (2005) and Grewe (2007, 2009). 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 it has been linked to their emotional qualities as well. 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 an approach to explain the emotional qualities conveyed by chords (e.g., Meyer (1956), and harmony's horizontal dimension might also influence vertical harmony perception. Tramo et al. for example (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 yielding a strong expectation to hear the tonic chord, even outside musical context.
In sum, chords have been implicated to convey “different emotional characteristics” in the past research but most of these studies regard chords within vertical and tonal

context. 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., Hevner, 1936; Lundin, 1985; Davies, 2010), according to previous empirical research there is little doubt that even such abstract and reduced musical stimuli as single isolated chords indeed do 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, isolated from all musical context) 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 not have reflected the more subtle variations of perceived emotions in single chords. Zentner et al. (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). The constructed 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 & 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 as an important general feature in regard to music and emotions (Juslin et al., 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 probably has more to do with psychophysical cues present in 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 understand the given terms (Appendix).

Method

Participants

The participants for the study were recruited through the internet with the aim of drawing the attention of both musicians and non-musicians and thus having a heterogeneous, large and international participant pool (see Honing & Ladinig, 2008 and Honing & Reips, 2008 for a review of the benefits of this strategy). The experiment was advertised in the social media (Facebook, LinkedIn) and on many mailing lists of different universities around the world. As an incentive, two €35 gift cards to Amazon.com were drawn between all participants who left their e-mail addresses within the experiment for this purpose. The total amount of answers was 289, out of which 281 were considered valid for further statistical analysis. Eight set of answers were annulled 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). Sixty-eight percent of the participants were between 17 and 29 years of age. Seventy-two percent of the participants reported having a university degree, making the participant pool very highly educated on average. The participants' musical sophistication was measured with the *Ollen Musical Sophistication Index* (Ollen, 2006), a ten-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 divider between a musician and a non-musician (see Marcs Auditory Laboratories, Internet 2). Non-musicians were divided into lower (OMSI score < 250, N=116) and higher (250 ≤ OMSI score < 500, N=54) groups respectively. The musicians were accordingly 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 1st and 2nd inversions respectively. Diminished (C°) 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 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 amount of chords relatively low and not to make the experiment too long for the participants. Thus, the stimuli were altogether 14 chords (Figure 1) played on 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 rendered to audio 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 strings 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 http://bit.ly/1ntHs7g

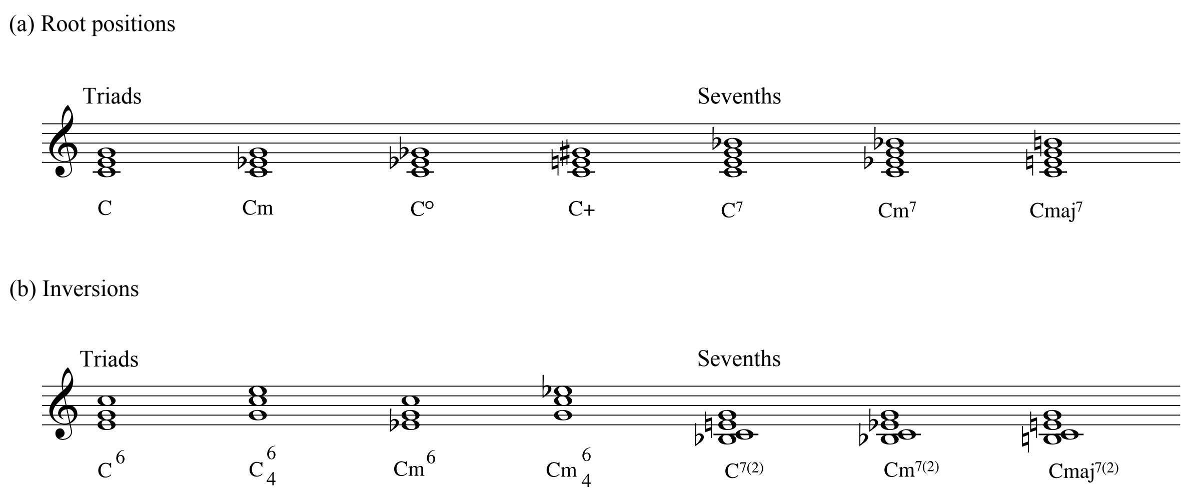

Figure 1. The chord stimuli.

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 9/12/2012 and 10/15/2012. 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 the 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*, 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 (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, 9 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 *happiness/joy* and *valence (.56)*. However, none of the dimensions demonstrate complete overlap with each other and most correlations are line with the past research using complete excerpts with a noteworthy exception of *valence* and *energy* (.48), which has not correlated in past studies (Eerola & Vuoskoski, 2011).

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).

Our subsequent analysis framework is repeated ANOVA. For each emotion dimension, we will carry out two main analyses (first overall analysis of chord type and timbre and then more precise analysis of chord qualities). These will be followed by three analyses of background variables (nationality, gender, and musical sophistication). To guard against inflated familywise error rates associated multiple testing, we will utilize Bonferroni corrections for the five subsequent analyses of each dimension. Moreover, any post-hoc analyses within the main analyses will also employ Bonferroni corrections. Since the design in some of the cases is not balanced (different amount of observations across chord inversions depending on the chord quality, e.g.

triads and seventh chords, Greenhouse-Geisser adjustment will also be 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 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.

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.

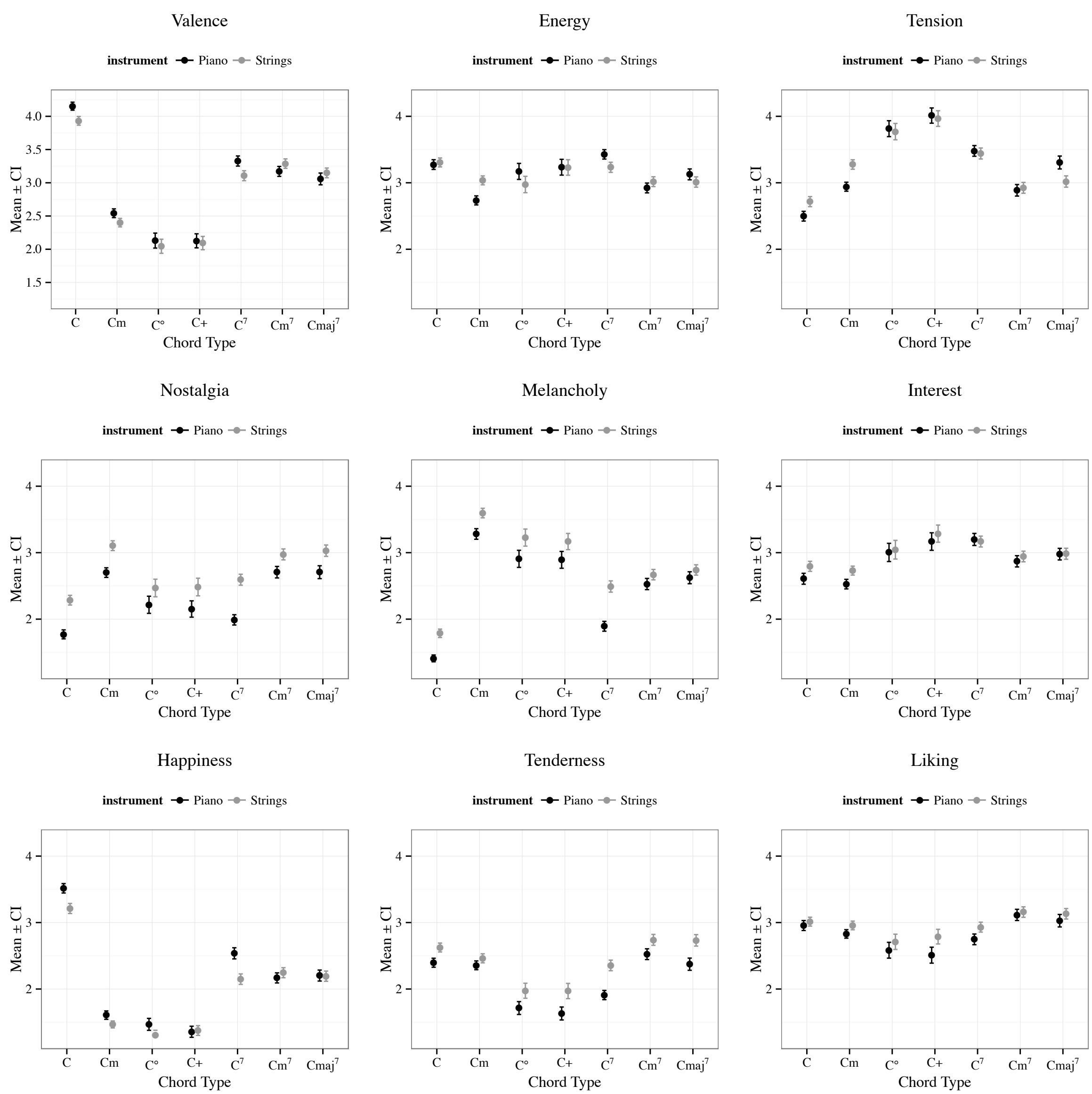

Figure 2. Mean ratings of the nine emotion dimensions across Chord Types and Instrument.

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), 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's mean of 3.99 (*SD* = 0.80), the second highest for the diminished triad's 3.79 (*SD* = 0.78) and the third highest for the dominant seventh's 3.46 (*SD* = 0.61). The lowest mean rating of *tension* was for the major triad's 2.61 (*SD* = 0.79), all which are statistically significantly different. Perceived *nostalgia/longing* was highest for the minor triad's mean of 2.90 (*SD* = 0.77), statistically on the same level as the major seventh's 2.89 (*SD* = 0.82) and the minor seventh's 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's 3.07 (*SD* = 0.98) and the augmented triad's 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's mean rating of 3.36 (*SD* = 0.81) followed by the dominant seventh's considerably lower 2.34 (*SD* = 0.80). The lowest *happiness/joy* mean rating was for the augmented triad's 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's 2.63 (*SD* = 0.82) followed by the major seventh's 2.52 (*SD* = 0.84). The lowest mean rating of *tenderness* was for the augmented triad's 1.80 (*SD* = 0.78).

Timbre. The most prominent differences of timbre to 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, η^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 is indisputably affecting the emotional connotations of the chords in 7 out of the 9 emotion scales. *Energy* and *tension* were the only emotion scales which did not exhibit a statistically significant difference of timbre in the ANOVA.

Inversions. The role of inversions for emotion ratings was compared with a 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 were contributing to the ratings particularly well 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 being the ones frequently featured in past emotion studies but also because they contain strong interactions between Inversions and Chord Types.

Table 3. Two-way ANOVA across Inversion and Chord Quality for all dimensions.

	Inversion		**Chord Qual.**		**Inv. × Chord Qual.**	
	F	η^2_G	F	η^2_G	F	η^2_G
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.

As we can see, with the major triad the tendency was that *valence*, *tension*, *energy* all exhibited an increasing pattern of root, 1st inversion and 2nd 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's 3.91 (*SD* = 0.92), through the 1st inversion's 4.22 (*SD* = 0.78) to the 2nd inversion's 4.32 (*SD* = 0.82). A similar pattern occurs at *interest/expectancy* and *happiness/joy* as well. 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 2.41 (*SD* = 0.94), 1st inversion 2.59 (*SD* = 0.98) and 2nd inversion 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 in the discussion part.

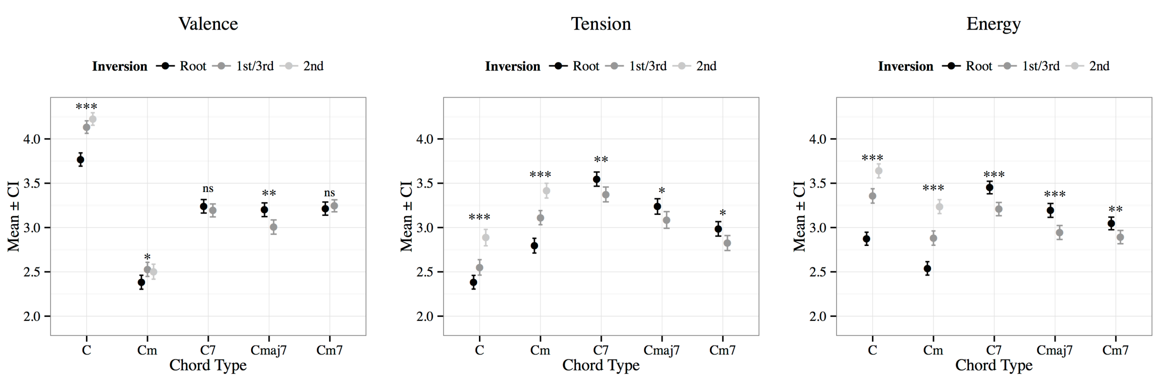

Figure 3. Mean ratings of the three emotion dimensions across Chord Types and Inversions (root, 1st and 2nd for triads, and root and 3rd for seventh chords).

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 most the mean ratings of the chords. 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 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 two biggest nationality groups' (US and Finland) mean ratings were compared to other nationalities' mean ratings. 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*, not the main emotion rating scales. Also the effect sizes revealed the relative insignificance of these differences. Still, musically more sophisticated participants evaluated the chords consistently in a somewhat stronger fashion (in some cases the opposite), according to musical conventions (Figure 4). As we can see, musicians for example rated the major seventh chord as having more tension while the major triad as having less tension when compared to the ratings of non-musicians. To elaborate 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 on both timbres. The most significant differences according to 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, $F\,(3, 265) = 9.75$, $p < .005$, η^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).

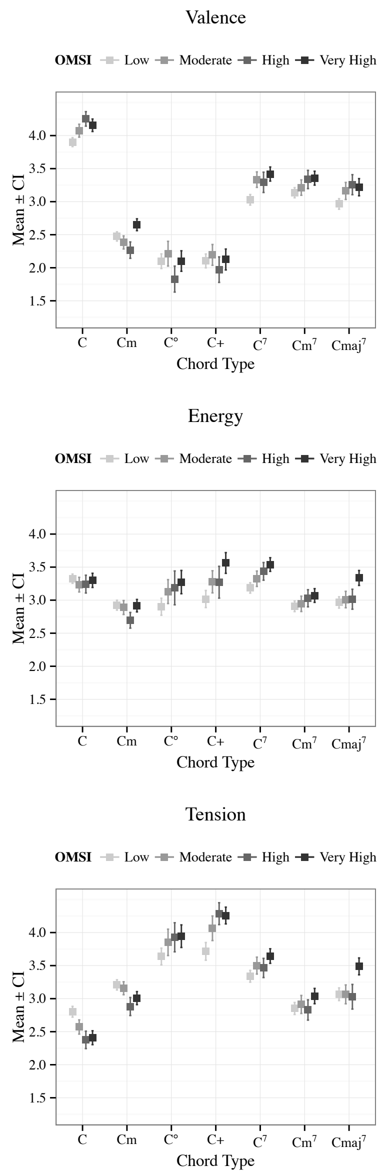

Figure 4. Mean ratings of the three emotion dimensions across Chord Types and Musical Sophistication.

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., Lundin, 1947; Cazden, 1980), others have posited that these are directly linked to psychoacoustic properties (e.g., Helmholtz, 1895/1980; Terhardt, 1974) whilst intermediate positions have also been proposed (Crowder, 1984; Juslin & Scherer, 2005; Cook & Fujisawa, 2006). 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., Zentner & Kagan, 1996; Trainor et al., 2002). 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), 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 is 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. 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 largely did not correlate 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 9-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 interaction 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 an increasing pattern of root, 1^{st} inversion and 2^{nd} inversion on 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 1^{st} and 2^{nd} inversions than in their root positions, the seventh chords' slightly higher values for the root positions than their 3^{rd} inversions also implying that the higher register yields more perceived *tension* and *energy* (for similar observations, see Ilie & Thompson, 2006; Costa et al., 2000). Still, with the major triad there's an interesting analogy with the chord's 2^{nd} 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 the 3^{rd}, 4^{th} and 5^{th} partials of the harmonic series following the 1^{st} and 2^{nd} partials (the root in two octaves). The major third's positive valence is usually seen emerging from its early presence in the harmonic series (e.g., Helmholtz, 1895/1980; Cooke 1959), though for example Ball (2010, p. 68) 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". Nonetheless, the positive valence of the major triad's 2nd 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 2^{nd} 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 of the chords depending on which timbre they were played on. 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 instruments 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 et al., 1996) or on the perception of emotions conveyed by speech prosody (Thompson et al., 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., in press).

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 at al. (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 in the current experiment we did not 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 necessarily automatically result in more preference with 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 people, 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* got surprisingly low mean ratings and was used mainly for the major triad. Also the dimension of *tenderness* got quite low mean rating 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 the control of the participants is definitely not as rigid as with a Lab-based approach, Goslin et al. (2004) and Honing & 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 indeed are 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 more elaborately and to 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 even single chords are able to convey.

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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.