Probe Tone Paradigm Reveals Less Differentiated Tonal Hierarchy in Rock Music

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Abstract

Krumhansl and Kessler's (1982) pioneering experiments on tonal hierarchies in Western music have long been considered the gold standard for researchers interested in the mental representation of musical pitch structure. The current experiment used the probe tone technique to investigate the tonal hierarchy in classical and rock music. As predicted, the observed profiles for these two styles were structurally similar, reflecting a shared underlying Western tonal structure. Most interestingly, however, the rock profile was significantly less differentiated than the classical profile, reflecting theoretical work that describes pitch organization in rock music as more permissive and less hierarchical than in classical music. This line of research contradicts the idea that music from the common-practice era is representative of all Western musics, and challenges music cognition researchers to explore style-appropriate stimuli and models of pitch structure for their experiments.

Keywords: tonal hierarchy, probe tone, pitch, popular music, style, tonality, perception

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The introduction of the probe tone paradigm by Krumhansl and colleagues (Krumhansl & Kessler, 1982; Krumhansl & Shepard, 1979) offered music cognition researchers a groundbreaking tool to investigate the mental representation of complex tonal structure (tonality). In their pioneering work, Krumhansl and Kessler demonstrated that given a simple musical context, listeners rated tones in accordance with music theoretical descriptions of the tonality. Specifically, in Western tonal-harmonic music, there are twelve possible *chromatic* tones which are arranged into a *tonal hierarchy*. Musical scales are composed of a subset of seven of the chromatic tones, called the *diatonic* set. The diatonic tones are further arranged into descending levels of hierarchy, consisting of the *tonic* (scale degree 1), the *tonic triad* (scale degrees 3 and 5), and the rest of the *diatonic tones* (scale degrees 2, 4, 6, and 7). This produces a tonal hierarchy with four levels, pictured in Table 1. In Krumhansl and Kessler's probe tone experiment, listeners produced a pattern of ratings that empirically reproduced the theoretical tonal hierarchy from Table 1 (Figure 1).

Krumhansl and Kessler's ratings have since been employed as an empirical model of Western tonality in a large variety of studies aimed at, for instance, developing key-finding algorithms (Krumhansl, 1990), investigating tonal effects on memory (Vuvan et al., 2014), and studying impacts of tonal structure on motor performance (Schmuckler et al., 2020). However, one key limitation of the use of this tonal profile in multiple Western music contexts is overgeneralization due to the assumption of its universality.

Specifically, the widespread use of Krumhansl and Kessler's ratings in diverse research contexts exposes an assumption by music cognition researchers that this ratings profile is an adequate descriptor of pitch structure across the multiple styles of Western music. This assumption is challenged by musicological research into intra-Western stylistic diversity. For example, de Clercq and Temperley (2011) performed an analysis of a subset of Rolling Stone magazine's "500 Greatest Songs of All Time", and concluded that although rock music shares significant features of tonal structure with common-practice (i.e., what is often colloquially termed "classical") music, there are some important differences. Specifically, they found that IV was the most common chord root after I; an important distinction from the common-practice distributions reported by Krumhansl, which place V further up the tonal hierarchy. Similarly, the bVII chord root was the third most frequent; considerably more common in their rock corpus than it was in any of the preceding classical corpora.

In the music theory literature, researchers have debated the prevalence of harmonic function in rock music (Moore, 1995), with some even suggesting that individual chords possess no inherent functional information and that they are interchangeable in some modal and pentatonic contexts (Björnberg, 2007). Similarly, music theorists have shown that melodic pitches in rock music are often misaligned or even "divorced" from their harmonic contexts (Nobile, 2015; Temperley, 2007). Temperley (2001) has theorized that rock music operates using a "supermode" that includes all scale degrees except the flattened second and sharpened fourth degrees.

In a test of this idea, Temperley and de Clercq (2013) calculated tone distributions extracted from melodic and harmonic transcriptions of the rock corpus presented in previous work (de Clercq & Temperley, 2011) These authors noted that tone distributions calculated from their rock corpus were highly similar in shape to those calculated from a common-practice (classical) corpus (Kostka et al., 2013; Temperley, 2001), reflecting a common Western tonal structure between styles. Despite these similarities, there were some structural differences between the classical and rock distributions. In particular, the classical distribution showed a higher value for the raised 7th scale degree than the lowered 7th, whereas the rock distribution showed the opposite.

This body of research thus provides support for the hypothesis that the tonal hierarchy for rock music differs from the tonal hierarchy for classical music. To go one step further, pitch organization in rock music may be more permissive than in classical music, which should be reflected in listener perceptions. These distinct perceptions of rock and classical tonality would lead participants to produce a tone profile in which there is less differentiation among ratings of probe tones in a rock context than in a classical context.

Differentiation of the perception of tonal hierarchy in classical and rock contexts has more recently been investigated in behavioural experiments. Craton et al (2016, 2019) have reported that participants show preferences for chords found to be common in the rock corpora, but their studies did not include comparing participant responses to ecologically valid stimuli in both the classical and rock contexts. Recently, we reported the results of an experiment in which participants heard a timbre-based style prime (Classical or Rock), followed by either a bVII-I or a V-I cadence (Vuvan & Hughes, 2019). Participants were required to rate the cadence in terms of how well it fit with the prime. Interestingly, although ratings for these cadences were significantly different for the classical prime, as expected, they were equivalent for the rock prime. This work provides initial evidence for the idea that listeners' tonal representations are sensitive to differences between rock and classical contexts, and that representations of rock harmony may be less differentiated than representations of classical harmony.

The goal of the current project was to extend our understanding of these differences from chords to tones, by quantifying the major tonal hierarchy for the classical and rock styles. We used the probe tone paradigm, presenting listeners with a key-defining context containing a style cueing timbre (solo piano for classical, electric guitar for rock), followed by a single timbre-matched tone that was rated in terms of its goodness-of-fit with the preceding context.

We predicted that the rating profile for rock music would be less differentiated than the rating profile for classical music. Further, we used correlation analyses to explore the extent to which the classical and rock tonal hierarchies were similar to each other, as well as to the "neutral" tonal hierarchy measured by Krumhansl and Kessler (1982), the minor tonal hierarchies measured by Vuvan et al. (Vuvan et al., 2011), and the corpus-derived probability distributions for rock and classical reported by Temperley and de Clercq (2013). We expected that the rock and classical tonal hierarchies would be highly correlated, as they reflect a common Western tonality. However, the classical ratings should be better correlated than the rock ratings with Krumhansl and Kessler's profile, whose "neutral" context better evokes common-practice than rock music, as well as Temperley and de Clercq's major key common-practice distribution, which reflects the content of listeners' exposure to classical music. On the other hand, the rock ratings should be better correlated than the classical ratings with Temperley and de Clercq's major key rock distributions, which would reflect the content of listeners' exposure to rock music. Finally, rock music often invokes modal mixture, which involves the borrowing of chords and notes from the parallel minor key, whereas modal mixture is considerably more rare in common-practice music (de Clercq & Temperley, 2011; Everett, 2004). Thus, we predicted that the rock ratings should be better correlated with Vuvan et al.'s and Temperley and de Clercq's minor profiles than the classical ratings.

Methods

Our experiment and confirmatory analysis plan was pre-registered on Open Science Framework. These materials, including our raw data and analysis code, can be viewed at www.osf.io/btc3w.

Participants

Participants (n = 37) were recruited through introductory music theory courses at the University of Lethbridge. All participants were compensated for their participation with course credit. The sample reported a mean age of 21.30 years (s = 2.37). Twenty-five participants reported their gender as "Female", 12 reported their gender as "Male", and 0 participants reported their gender as "Neither / Other". Twenty-eight participants reported formal musical training, with a mean duration of 6.95 years (s = 5.79), and a mean age of onset of 10.04 years (s = 5.54). Twenty participants reported currently playing music, with a mean time spent playing per week of 12.00 hours (s = 11.64).

Materials

All stimuli were assembled in the Reaper 5.981 Digital Audio Workstation environment. All stimuli were composed using the Kontakt 5 sampling platform with

MIDI instruments selected from Native Instruments' Kontakt Komplete 11 libraries to best emulate classical or rock styles. Rock stimuli were produced using the Electric Sunburst MIDI instrument and Hi Gain Rock School amp setting to emulate an electric guitar. Classical stimuli were produced using The Grandeur MIDI instrument to emulate a grand piano.

Each excerpt consisted of a cadence (I - IV - V - I) that established the key context (see Figure 2), followed by a probe tone. The excerpt was played at 120 beats per minute (500 ms per beat). Each chord in the cadence lasted two beats (1000 ms). Following the cadence, there was a one beat (500 ms) silence, followed by the probe tone, which lasted two beats (1000 ms). The probe tone was always presented at a pitch height within the octave below the highest tonic pitch in the context (Figure 2). To create repetitions, the excerpts were presented in eight different keys (A, A♭, B, B♭, D, D♭, E, E♭). Combining this series of manipulations resulted in a total of 192 experimental excerpts (2 Styles x 12 Probe Tones x 8 Keys).

The experimental stimuli were presented on a computer running OpenSesame 3.1 (Mathôt et al., 2012), and responses were collected via mouse click. Participants were tested in a quiet room, with sound presented using closed back headphones.

Procedure

Trials were presented in two style blocks: Rock and Classical. The order of presentation of these blocks were counterbalanced between participants. Participants were not told the order in which the blocks would proceed. Before beginning the trial blocks, participants were given 6 practice trials chosen randomly from one of either the classical or rock block. Following the practice trials, participants were given the following instructions:

> "There will be two blocks of trials. One with piano sounds, and one with distorted electric guitar sounds. The second of these two blocks of trials will occur half way through the experiment. When the experiment is finished, you will see a message thanking you for your participation."

On each trial participants were given the following instructions:

> "You will now hear a short excerpt of music, followed by a single tone. Immediately following the single tone, you will be asked to respond with a rating from 1-7. Note that we're only interested in your intuition. You will have only 4 seconds to respond, so try to respond quickly and don't concern yourself with whether or not you get the 'right answer.'"

The experimental session lasted approximately 30 minutes.

Results

Intersubject Correlations

As a first step, we calculated intersubject correlations in order to quantify the degree of consistency in ratings across participants. A 24-point ratings vector was calculated for each participant (collapsing across Key, which was considered a repetition variable), providing an average rating for each of the 12 probe tones, in both styles. Correlations were then calculated across each of these participant vectors. The average intersubject correlation was $r(22) = .40$, $p = .05$, range [-.58, .97]. The average intersubject correlation was not meaningfully different between Classical, $r(22) = .43$, $p = .04$, range [-.84, .98], and Rock, $r(22) = .43$, $p = .04$, range [-.79, .98]. One can compare for reference, Krumhansl and Kessler (1982), who observed an average intersubject correlation of .59 for their major and minor tonal profiles, and Vuvan, Prince, and Schmuckler (2011), who observed an average intersubject correlation of .27 for their minor tonal profiles. Thus, although there were significant differences between participants' tonal profiles, our participants as a group showed a substantial amount of agreement in their tonal ratings for both classical and rock music. This agreement allowed us to calculate aggregate profiles for classical and rock, which were submitted to the correlation analyses reported below.

Effects of Style on Tonal Hierarchy

Omnibus ANOVA. Ratings were submitted to repeated measures ANOVA, with Style (Classical, Rock) and Probe Tone (1-12) as within-subjects factors. There was no significant main effect of Style, $F(1,27) = 0.36$, $p = .55$, $GES = .004$, indicating that the average rating across all probe tones was equivalent for Classical and Rock. As predicted, there was a significant main effect of Probe Tone, $F(1,27) = 80.88$, $p < .001$, $GES = .60$, indicating substantial variability in ratings across probe tones. Finally, as predicted, there was a significant interaction between Style and Probe Tone, $F(1,27) = 8.50$, $p = .007$, $GES = .06$. This interaction suggests that the pattern of probe tone ratings (i.e., the tonal hierarchy) differed between Classical and Rock (Figure 3).

Further characterizing this Style by Probe Tone interaction, the classical tonal hierarchy consisted of a larger spread of values ($s = 0.86$; range = 2.72) than the rock tonal hierarchy ($s = 0.79$, range = 2.63). This difference is consistent with the theoretical description of the rock profile being less differentiated than the classical profile.

Effect of musicianship. To explore whether musicianship had an effect on our observed results, we submitted the ratings to a repeated measures ANCOVA with Style

(Classical, Rock) and Probe Tone (1-12) as within-subjects factors, and years of self-reported formal musical training as a covariate. The results were identical, with no main effect of Style, $F(1,27) = 0.36$, $p = .55$, $GES = .004$, a significant main effect of Probe Tone, $F(1,27) = 80.88$, $GES = .60$, and a significant Style x Probe Tone interaction, $F(1,27) = 8.50$, $p = .007$, $GES = .06$. A second ANCOVA in which age of onset of formal musical training was substituted for years of training again yielded the same pattern of results, with no main effect of Style, $F(1,27) = 0.36$, $p = .55$, $GES = .004$, a significant main effect of Probe Tone, $F(1,27) = 80.88$, $GES = .60$, and a significant Style x Probe Tone interaction, $F(1,27) = 8.50$, $p = .007$, $GES = .06$. Thus, musicianship did not play a meaningful role in the effects of style observed in these data.

Tonal hierarchy correlations. To further characterize the differences between our classical and rock tonal hierarchies, we ran a series of correlation analyses that compared our classical and rock profiles to each other, as well as other tonal hierarchies that have been previously published (Table 2). These tonal hierarchies included four probe tone rating profiles from behavioural experiments and six frequency of occurrence profiles from corpus analyses. The four behavioural profiles were the major profile from Krumhansl and Kessler (1982) and the three minor profiles from Vuvan et al.(2011). The six corpus profiles were major and minor profiles for each of a rock melody corpus, a rock harmony corpus, and a classical corpus, all reported by Temperley and de Clercq (2013).

As a first step, we collapsed ratings for each style and probe tone across all participants to obtain a “classical profile” and a “rock profile” from our data (Figure 3). Our classical and rock profiles were highly correlated, $r(10) = .93$, $p < .001$. Thus, although the significant Style x Probe Tone interaction suggests that the classical and rock profiles differ meaningfully from one another, they also reflect a shared underlying Western tonal structure, the shape of which can be seen in Figure 1.

Next, we correlated our classical and rock profiles with the previously published tonal hierarchy profiles described above. These correlations allowed us to better describe the differences between the classical and rock profiles. Then, to confirm these descriptive differences using inferential statistics, we calculated correlations matrices for each participant (classical and rock profiles correlated with each of the five previously published tonal hierarchy profiles described above). The correlations in these participant matrices were transformed using Fisher's r-to-z transformation to obtain normally distributed z scores, and then these z scores were submitted to paired samples t tests to reveal whether the classical and rock profiles differed significantly in their correlations to each of the test profiles.

Please note that only the analyses involving the Krumhansl and Kessler (1982) and the Vuvan et al. (2011) profiles were pre-registered and were assessed with critical $p = .05$. The analysis with Temperley and de Clercq's (2013) profiles were considered exploratory and were assessed at critical $p = .05/6 \text{ tests} = .008$.

Correlations with Krumhansl and Kessler major profile. We predicted that Krumhansl and Kessler's major profile better reflects a classical music context than it does a rock music context. This prediction was confirmed descriptively, with the Krumhansl and Kessler profile correlating better with our classical profile than our rock profile (Table 2). However, a paired samples t test performed on our participant further substantiated this claim, with participants' classical profiles correlating significantly higher with the Krumhansl and Kessler major profile than did their rock profiles, t(36) = 2.31, p = .03, d = 0.38. Figure 4 shows that this effect is subtle, but systematic.

Correlations with Vuvan, Prince, and Schmuckler parallel minor profiles. We predicted that the rock profile would have a higher correlation with the parallel minor tonal hierarchies than would the classical profile. Interestingly, this prediction was not confirmed descriptively, with the classical (major) profile showing higher correlations with Vuvan et al.'s minor profiles, regardless of which minor type - natural, harmonic, or melodic - was tested (Table 2).

As can be seen in Figure 5, paired samples t tests performed on our participant correlations further substantiated this result, with participants' classical profiles correlating significantly higher than their rock profiles with the parallel natural minor, $t(36) = 2.71$, $p = .01$, $d = 0.45$, harmonic minor, $t(36) = 4.17$, $p = .0002$, $d = 0.69$, and parallel melodic minor, $t(36) = 4.27$, $p = .0001$, $d = 0.70$.

Correlations with Temperley and de Clercq profiles. Finally, we correlated our classical and rock profiles with Temperley and de Clercq's (2013) six corpus profiles (rock melody major, rock melody minor, rock harmony major, rock harmony minor, classical major, classical minor). We predicted that our empirically derived rock profile should be better correlated with the statistics of actual rock music than our classical profile, and vice versa. Furthermore, we expected that our rock profile would show a higher correlation with the minor corpus profiles than would the classical profile.

Our predictions were not borne out by the data. As can be seen in Table 3, the rock corpus profiles correlated almost equally with our classical and rock ratings. A paired samples t test performed on our participant correlations further substantiated this observation, with no significant difference in correlations between participants' classical and rock ratings and the rock melody major distribution, $t(36) = 0.31$, $p = .76$, $d = 0.05$, the rock melody minor distribution, $t(36) = 0.36$, $p = .72$, $d = 0.06$, or the rock harmony minor distribution, $t(36) = 0.78$, $p = .44$, $d = 0.13$. There was a marginally significant difference for the rock harmony major distribution, $t(36) = 2.91$, $p = .006$, $d = 0.48$, such that correlations were slightly higher for the classical profile than for the rock profile. Interestingly, our behavioural profiles seem to reveal a greater degree of differentiation between rock and classical than do the corpus profiles (Figure 6), which may underlie the lack of correspondence observed in the current analyses.

With regard to the classical corpus profiles, our classical ratings appeared to correlate better than our rock ratings with both the classical major and minor corpora. However, these nominal differences were not borne out by paired comparisons. There was no significant difference in correlations between participants' classical and rock ratings and the classical major distribution, $t(36) = 2.23$, $p = .03$, $d = 0.37$, or the classical minor distribution, $t(36) = 1.13$, $p = .26$, $d = 0.19$.

Discussion

In the current experiment, listeners heard short excerpts that primed a major tonality in either the classical or rock style. Participant responses were in high agreement with one another, providing evidence that the aggregated tonal hierarchy profiles measured for classical and rock are reasonably generalizable across individuals. As predicted, the profiles for the two styles were distinct, with a less differentiated hierarchy for rock compared to classical, but also reflecting a shared underlying Western tonal structure. Correlation analyses revealed that the classical profile was significantly better correlated than the rock profile with the major ratings profile from Krumhansl and Kessler (1982) and the minor ratings profiles from Vuvan et al. (2011). However, the classical and rock ratings profiles did not correspond well to distributions found in existing major and minor classical and rock corpora from Temperley and de Clercq (2013).

Our central hypothesis, that the rock tonal hierarchy is less differentiated than the classical tonal hierarchy because of rock's more permissive tonal structure, was confirmed. Moreover, listeners' style-specific representations can be evoked using a simple timbral cue, as the classical and rock excerpts were identical except for the instrument they employed. In previous work Vuvan and Hughes (2019) demonstrated that reducing the number of style cues available to listeners weakens the distinction between tonal representations for classical and rock. Thus, in the current experiment, the successful instantiation of distinct tonal hierarchies for classical and rock with minimal stylistic manipulation is notable.

The motivation for using this minimal stylistic manipulation was to keep our stimuli as controlled (in terms of pitch, rhythm, number of onsets and durations) as possible. This control allows us to make a stronger claim about the contribution of top-down knowledge about the pitch structure of different styles. It is possible that the distortion applied to the guitar could have affected the listener's perception of the rock tonal hierarchy in a meaningful way, given its impact on the presence of various partials heard throughout the harmonic series. However, we find no evidence in our data that listener ratings for the rock stimuli were less reliable than those for the classical stimuli. One could indeed hypothesize that distortion is the sole reason for the differentiated tonal hierarchies in our experiment. We argue, however, that its presence was a necessity for conveying a sense of rock's style, in which distorted electric guitar is a hallmark. To tease apart the degree to which guitar distortion is responsible for conveying this sense of style is a difficult and necessary question that we hope to engage in future research.

Overall, our results indicate that participants have clearly distinguishable representations of the classical and rock tonal hierarchies, and that these representations can be activated with a single stimulus cue (in this case, timbre). That said, it is possible that expanding the number of stylistic cues presented to listeners might produce more divergent mental representations for the classical and rock styles, and show a more divergent pattern of correlations with the comparison profiles we tested in the current experiment.

Discourse in music theory scholarship dealing with harmony in popular music has produced varied opinions with regard to its overlap with common-practice repertoire. Walter Everett (1999, 2004) among others, embraces a more unified approach to tonal practice in both rock and common-practice music. Other scholars, such as Ken Stephenson (2002), Allan Moore (Moore & Martin, 2018), Alf Björnberg (2007), and Phillip Tagg (2014) have argued that rock's tonal system is meaningfully distinct from that demonstrated by common-practice repertoire. More recently, computational analyses of various rock corpora (Acevedo, 2017; Burgoyne et al., 2011; de Clercq &

Temperley, 2011; Temperley & de Clercq, 2013) have suggested a tonal system that resembles that used in common-practice music, but with some important differences. Notably, the flattened seventh scale degree occurs more frequently in rock music than it does in common-practice repertoire (Temperley & de Clercq, 2013). This result is reflected by listener judgments of chords (Vuvan & Hughes, 2019). The results of the current study expand this account to show that the listener representations of the tonal hierarchy in rock music are less differentiated than in classical music.

As noted above, our rock and classical profiles were equally correlated to the Temperley and de Clercq corpus profiles. Given that these authors' major key rock profile was only strongly differentiated from a standard classical profile for certain tones, i.e., the flattened-seventh scale degree, and that our style primes did not contain this scale degree, it is possible that our rock primes sounded more like weak representations of classical music than a strong representation of rock music. It is possible that tone distributions based on larger more representative corpora of rock and classical music might correspond more clearly with our ratings profiles.

Also unexpected was the higher correlation between the Vuvan et al. minor key profiles and our classical profile than with our rock profile. Given that our primes provided an unambiguously major-key context, the rock profile's weaker correlation to the Vuvan et al. minor-key profile makes sense. Absent the modal mixture that rock music usually employs, participants may have heard the rock primes as only weakly depicting the style. In this case, their judgments would have been guided by the bottom-up input which was strongly major. Thus, one goal of future work will be to elucidate which and how many stylistic cues are required to elicit various theorized aspects of pitch structure in rock music. Another important objective will be to test our paradigm using minor key primes in order to better understand the way that modes are represented by listeners in rock contexts.

Some of our recent work (Hughes & Vuvan, 2018) has already demonstrated that increasing the number of stylistic cues in a musical prime can produce stronger differentiation between listener responses to classical and rock music. The current study thus adds to a growing body of scholarship finding evidence for listener representations of pitch structure that are highly sensitive to stylistic context. This line of research contradicts the idea that music from the common-practice era is representative of all Western musics, and challenges music cognition researchers to explore style-appropriate stimuli and models of pitch structure for their experiments.

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Table 1

Theoretical tonal hierarchy

Hierarchy level	Scale degree
Tonic	1
Tonic triad	3 5
Diatonic tones	2 4 6 7
Non-diatonic tones	(5 non-scale tones)

Table 2

Tonal hierarchy profiles

Chromatic Tone	Classical ratings	Rock ratings	K&K major ratings	Vuvan natural minor ratings	Vuvan harmonic minor ratings	Vuvan melodic minor ratings	T&dC rock melody major distribution	T&dC rock melody minor distribution	T&dC rock harmony major distribution	T&dC rock harmony minor distribution	T&dC classical major distribution	T&dC classical minor distribution
0	5.38	5.34	6.35	5.08	4.62	4.75	0.223	0.317	0.231	0.202	0.226	0.207
1	2.65	3.33	2.23	3.03	2.63	3.26	0.001	0.001	0.002	0.006	0.009	0.016
2	3.39	3.73	3.48	3.73	3.74	3.76	0.158	0.090	0.091	0.102	0.100	0.086
3	3.01	3.39	2.33	4.23	4.23	4.46	0.015	0.159	0.004	0.127	0.018	0.144
4	3.62	3.95	4.38	3.64	3.63	3.49	0.194	0.046	0.149	0.047	0.153	0.009
5	3.96	3.99	4.09	3.85	3.81	4.09	0.071	0.097	0.111	0.113	0.101	0.093
6	2.83	2.82	2.52	3.13	4.15	3.67	0.002	0.007	0.004	0.005	0.018	0.018
7	4.93	4.54	5.19	5.29	5.21	5.08	0.169	0.131	0.193	0.177	0.192	0.235
8	2.9	2.9	2.39	4.43	4.77	4.14	0.003	0.009	0.004	0.046	0.024	0.088
9	3.38	3.21	3.66	3.95	3.95	4.43	0.119	0.047	0.126	0.051	0.075	0.010
10	2.91	2.88	2.29	5.26	3.79	4.51	0.008	0.087	0.011	0.090	0.014	0.029
11	3.03	2.71	2.88	3.99	5.3	4.91	0.035	0.009	0.076	0.034	0.069	0.063

Note. K&K ratings are from Krumhansl & Kessler (1982). Vuvan ratings are from Vuvan et al. (2011) and are the parallel (not relative) minor. T&dC ratings are from Temperley & deClercq (2013). Behavioural ratings are reported to 2 decimal places, as they were originally published by Krumhansl & Kessler and Vuvan et al. Temperley & deClercq's distributions are reported to 3 decimal places, in the same form they were received via personal correspondence with Temperley (2020).

Table 3

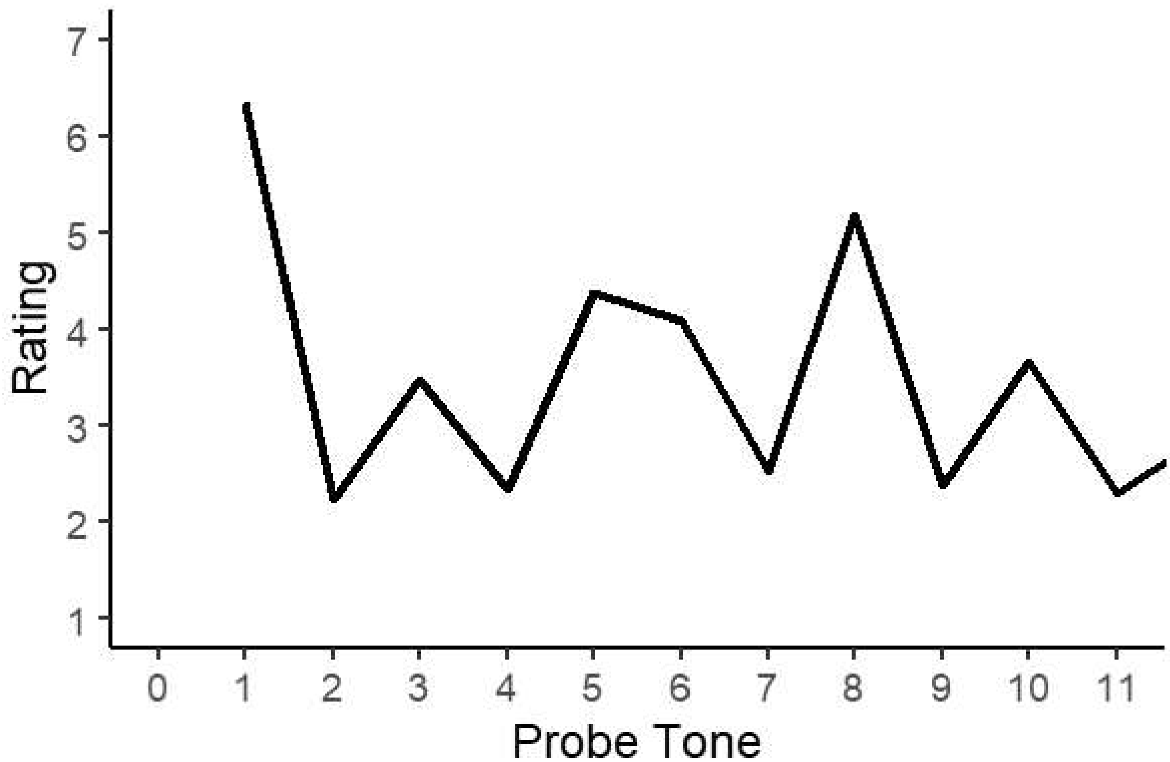
Bivariate correlations between all tonal hierarchy profiles

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11
1. Classical Ratings	3.50	0.86											
2. Rock Ratings	3.57	0.79	.93** [.77, .98]										
3. K&K Major Ratings	3.48	1.32	.97** [.89, .99]	.92** [.73, .98]									
4. Vuvan Natural Minor Ratings	4.13	0.76	.57 [-.01, .86]	.40 [-.23, .79]	.43 [-.20, .80]								
5. Vuvan Harmonic Minor Ratings	4.15	0.74	.40 [-.23, .79]	.11 [-.49, .64]	.31 [-.32, .75]	.57 [-.01, .86]							
6. Vuvan Melodic Minor Ratings	4.21	0.58	.50 [-.11, .83]	.23 [-.40, .71]	.37 [-.26, .78]	.80** [.42, .94]	.81** [.45, .95]						
7. T&dC Melody Major Distribution	0.08	0.08	.82** [.46, .95]	.82** [.47, .95]	.91** [.69, .97]	.29 [-.34, .74]	.15 [-.46, .67]	.19 [-.43, .69]					
8. T&dC Melody Minor Distribution	0.08	0.09	.79** [.39, .94]	.82** [.46, .95]	.71** [.23, .91]	.61* [.06, .88]	.24 [-.39, .72]	.48 [-.13, .83]	.58* [.01, .87]				
9. T&dC Harmony Major Distribution	0.08	0.08	.92** [.74, .98]	.84** [.52, .96]	.97** [.91, .99]	.40 [-.22, .79]	.33 [-.30, .76]	.41 [-.22, .80]	.93** [.76, .98]	.61* [.06, .88]			
10. T&dC Harmony Minor Distribution	0.08	0.06	.84** [.52, .95]	.81** [.44, .94]	.72** [.25, .92]	.75** [.32, .93]	.39 [-.24, .79]	.62* [.07, .88]	.59* [.03, .87]	.91** [.71, .98]	.65* [.13, .89]		
11. T&dC Classical Major Distribution	0.08	0.07	.94** [.80, .98]	.89** [.66, .97]	.98** [.93, .99]	.43 [-.20, .80]	.35 [-.28, .77]	.37 [-.26, .78]	.93** [.77, .98]	.65* [.13, .89]	.98** [.91, .99]	.70* [.21, .91]	
12. T&dC Classical Minor Distribution	0.08	0.08	.77** [.36, .93]	.71** [.23, .91]	.62* [.07, .88]	.66* [.15, .90]	.59* [.03, .87]	.65* [.12, .89]	.43 [-.19, .81]	.76** [.33, .93]	.54 [-.05, .85]	.89** [.64, .97]	.62* [.07, .88]

Note. M and SD are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. * indicates $p < .05$. ** indicates $p < .01$. K&K ratings are from Krumhansl & Kessler (1982). Vuvan ratings are from Vuvan et al. (2011) and are the parallel (not relative) minor. T&dC ratings are from Temperley & deClercq (2013).

Figure 1

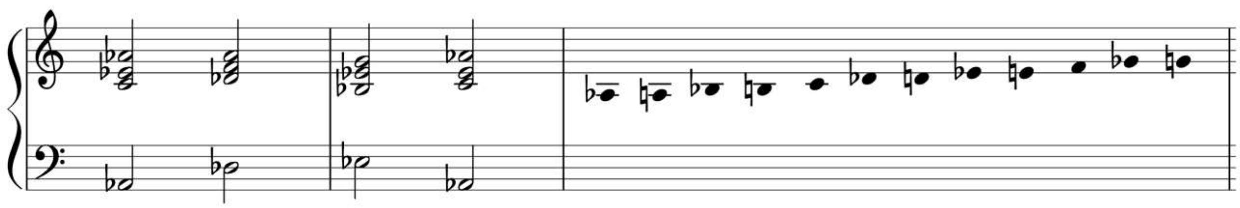
Krumhansl & Kessler's (1982) major probe tone ratings



Note: Adapted from values published by Krumhansl (1990). Probe tone 0 = Scale degree 1.

Figure 2

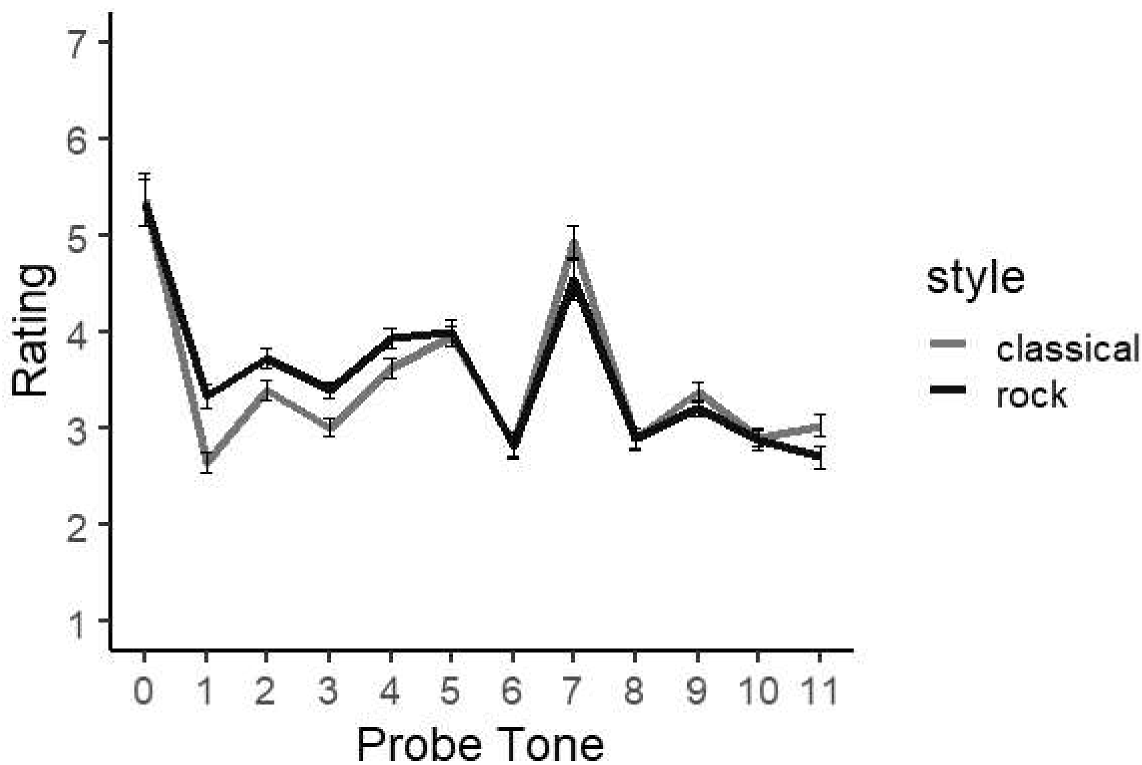
Tonal context for each trial, followed by the twelve probe tones



Note: Trials were presented in eight different keys (A, A♭, B, B♭, D, D♭, E, E♭), with the range of the probe tones adjusted according to the transposition. For example, the trials in A♭ major includes probe tones ranging from A♭3 to A♭4.

Figure 3

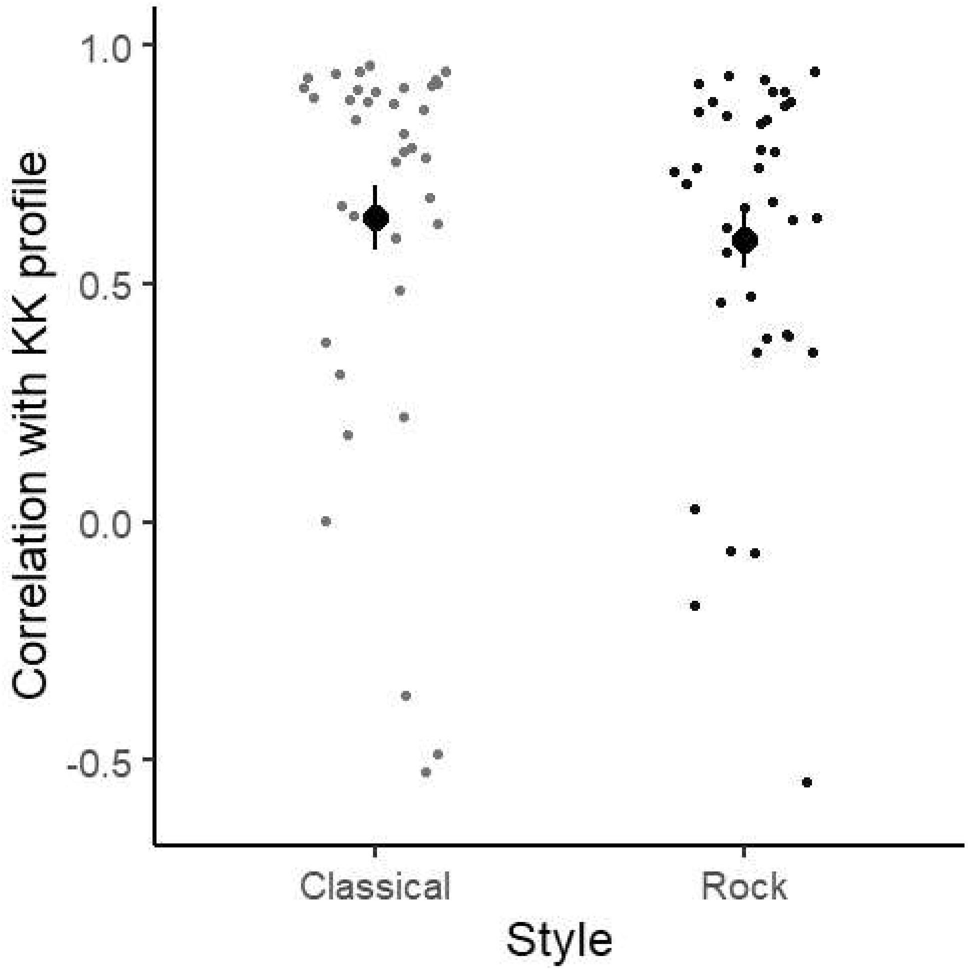
Tonal hierarchy for classical and rock contexts (probe tone ratings)



Note: Error bars display within-subject standard error.

Figure 4

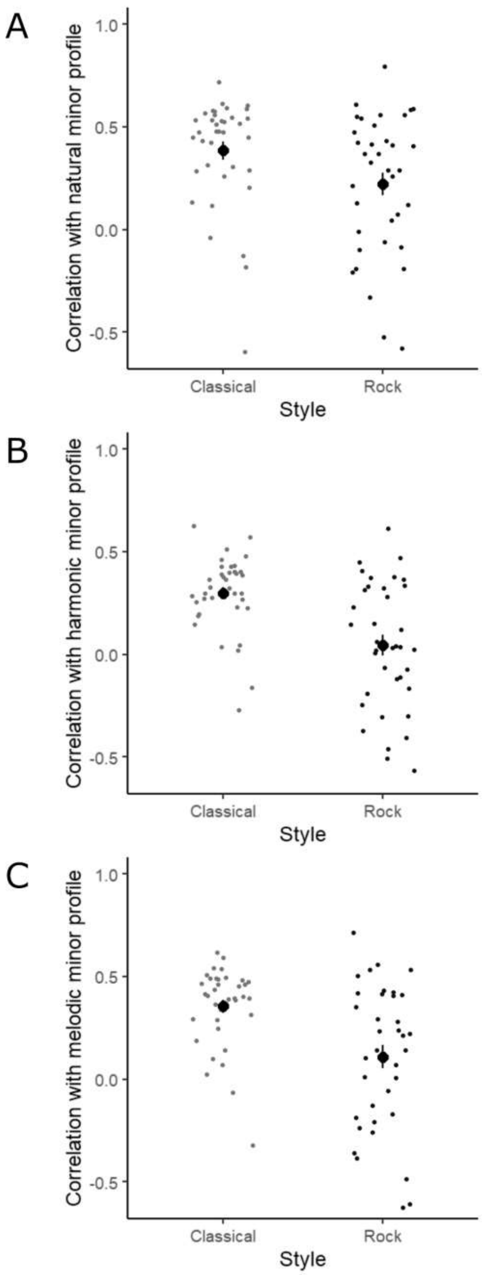
Correlations between classical and rock tonal hierarchies and the Krumhansl & Kessler major tonal hierarchy



Note: Each coloured dot represents a participant and the heavy black dot displays the mean and standard error.

Figure 5

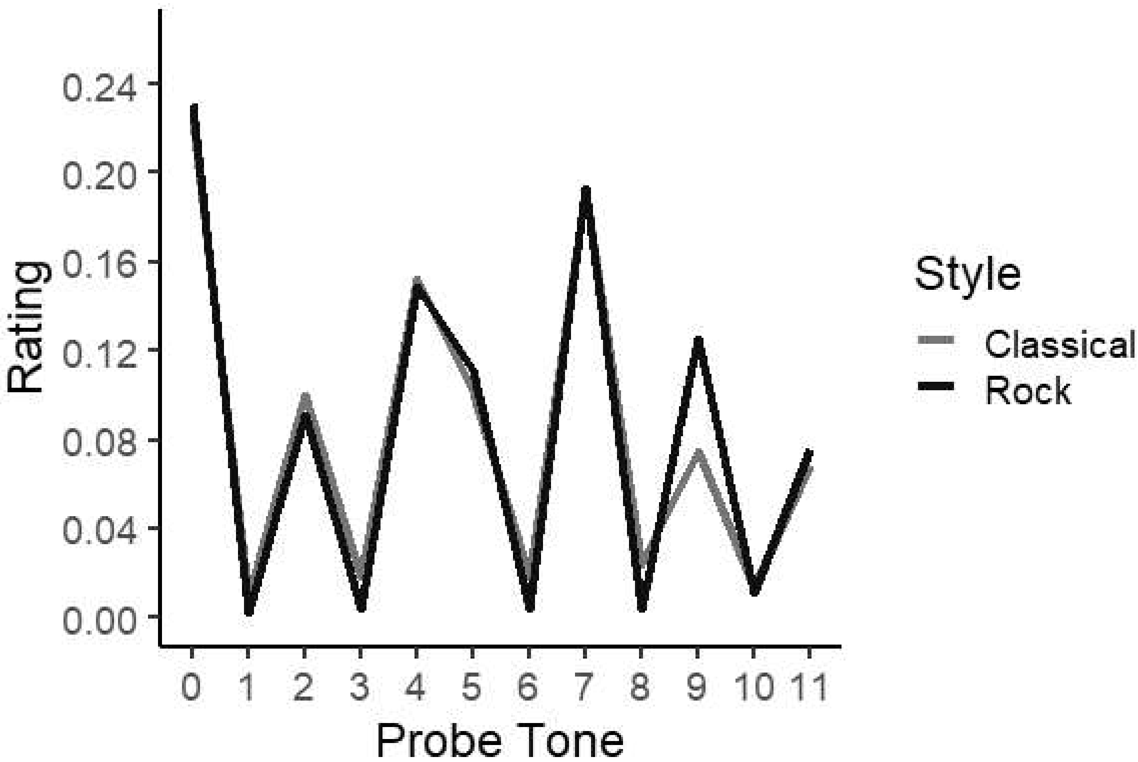
Correlations between classical and rock tonal hierarchies and natural, harmonic, and melodic minor tonal hierarchies



Note: Each coloured dot represents a participant and the heavy black dot displays the mean and standard error. (A) Natural minor; (B) Harmonic minor; (C) Melodic minor.

Figure 6

Tonal hierarchy for classical and rock contexts (corpus distributions)



Note: The classical distribution is the T&dC classical major distribution, and the rock distribution is the T&dC rock harmony major distribution (see Table 2).