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Perceived Emotions of Harmonic Cadences

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Abstract

Harmonic cadences are chord progressions that play an important structural role in Western classical music – they demarcate musical phrases and contribute to the tonality. This study examines participants' ratings of the perceived arousal and valence of a variety of harmonic cadences. Manipulations included the type of cadence (authentic, plagal, half, and deceptive), its mode (major or minor), its average pitch height (the transposition of the cadence), the presence of a single tetrad (a dissonant four-tone chord), and the mode (major or minor) of the cadence's final chord. With the exception of average pitch height, the manipulations had only small effects on arousal. However, the perceived valence of major cadences was substantially higher than for minor cadences, and average pitch had a medium-sized positive effect. Plagal cadences, the inclusion of a tetrad, and ending on a minor chord all had weak negative effects for valence. The present findings are discussed in light of contemporary music theory and music psychology, as knowledge of how specific acoustic components and musical structures impact emotion perception in music is important for performance practice, and music-based therapies.

Keywords

Arousal, cadence, emotion, perception, valence

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Introduction

Tension and release play an important role in listeners' experience of Western classical music (Huron, 2006; Meyer, 1956). In such music, the interplay between tension and release is perhaps most clearly expressed by *harmonic cadences* (Lowinsky, 1961; Milne, 2009a, 2013) – defined here as specific sequences of chords that are used at the ends of musical phrases to induce differing degrees of closure. In research, perception of cadences has so far been related to expectancy. (e.g. Egermann & McAdams, 2013; Lehne et al., 2014; Meyer, 1956; Sears et al., 2018, 2020; Tillmann & Marmel, 2013), but there have been contradictory results regarding the impact on perceived emotion in the listener. Psychoacoustical similarity and fit of cadences has been tested in Milne (2009b, 2010) and Milne et al. (2015). With the increased interest in the relationship between music and emotions (e.g. Egermann et al., 2015; Juslin & Västfjäll, 2008; Lahdelma & Eerola, 2016; Smit et al., 2019), it is essential to understand perceived affect of musical structures such as harmonic cadences. Therefore, this study will examine the effect of several manipulations: cadence type, major/minor mode, the inclusion of a tetrad (a dissonant four-tone chord), average pitch, and the mode of the final chord on arousal and valence responses to a number of common Western harmonic cadences, to see how those contribute to affect perception.

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Background Literature

Originating from the Latin term "caderer" (to fall), the cadence has gained multiple definitions over the course of history, such as "a strong key defining sequence of chords that most frequently contains the V and I chords of the new key" (Krumhansl & Kessler, 1982, p. 352). As described by Caplin (2004), qualities associated with the term "cadence" have transformed over the years and can now include information about, for example, the final chord, the harmonic progression, and the modality. A fundamental aspect essential to the classical cadence is that it leads to a formal conclusion of a musical phrase (Caplin, 2004). Cadences can be discussed in light of their melodic and harmonic features; the focus of this paper will be on harmonic aspects.

The diversity of cadence definitions is partly due to changes in musical traditions and contexts over time, either local or more general, leading to a large number of different cadence types (Neuwirth & Bergé, 2015). Examples of such cadence types are the authentic cadence (V – I, or V – i), the plagal cadence (IV – I), half cadences (e.g. I – V), and the deceptive cadence (e.g. V – vi). Importantly, Roman numerals indicate both the chord's root note and its mode (upper case meaning major, lower case meaning minor). Neuwirth and Bergé (2015) questioned whether different cadence types lead to distinct forms of closure and suggest that variations in cadence types might therefore be "better understood as transformations of an ideal prototype, the perfect authentic cadence" (p. 9). Based on this idea, we questioned whether within-cadence type variations lead to a change in affective perception of cadences. For example, does adding a seventh to the penultimate dominant type chord have a significant effect on the perception of that cadence as a whole? Or, as Neuwirth and Bergé (2015) state, "should such features just be regarded as expendable embellishments?" (p. 9).

Most current literature on the perception of cadences has contextualized these questions in relation to expectancy (e.g. Sears et al., 2018, 2020). Cadences have an element of predictability, as they often function according to similar principles. Huron (2006) points out that this predictability is related to phrase boundaries in speech. Higher degrees of predictability are required for clear distinction of phrase boundaries, both in speech and in music. The psychological mechanism behind musical expectancy, which refers to the idea that violations of listeners' predictions induce emotions (Juslin & Västfjäll, 2008), has been put into theory by Meyer (1956) and refers to expectancies that are related to the syntax of a musical structure (Juslin & Västfjäll, 2008; Narmour 1991; Patel, 2003). Expectations lead to emotional experiences; fulfilled expectations to positive and unfulfilled expectations as negative (Huron, 2006).

In an experiment by Egermann et al. (2013), emotional responses to violations and confirmations of musical expectations were examined in an audience listening to a live flute concert. Musical events with low conditional probability led to increased arousal and decreased valence ratings, therefore supporting the idea that there is a relationship between musical events, violation of expectations and emotional responses.

A number of studies have shown that unexpected or surprising musical events lead to high arousal and low valence responses (Egermann et al., 2013; Koelsch et al., 2008; Steinbeis et al., 2006), but contradictory, unexpected events can also evoke a high valence response (Huron, 2006). By examining the arousal and valence responses of several cadence types, this study aims to contribute to this area of research.

Inspired by Neuwirth and Bergé (2015), we were also interested in whether the presence of a dissonant interval in a cadence would have an effect on emotional responses. A property of a dissonant interval is that it creates tension and seeks to be resolved into a consonant interval. Dissonant notes are often used in cadences (such as added 7ths or 9ths), and are often used to add some extra "color" or tension. However, by adding an extra dissonant note to a cadence, its music-structural function presumably remains the same, unless it is the final chord that is transformed to a tetrad. We were interested in the affective perceptual impact of adding such a note to a cadence in order to answer the question whether such notes are merely "embellishments" (Neuwirth & Bergé, 2015) and simply provide some extra "color" to the chord, or whether they have an essential impact on the perception of the cadence as a whole.

An important parameter of a cadence is its mode. In music theory, "mode" has at least two meanings: it can refer to scales such as Ionian, Mixolydian, Aeolian, Dorian, and so forth; alternatively, it can refer to keys or chords, which are either "major" or "minor". Here, we use "mode" only in the latter sense. It is well acknowledged that the mode of a musical item has an impact on its perceived happiness. For example, pieces that are written in a major key are often perceived to be happy or joyful, whereas a minor key is associated with sadness (e.g. Crowder, 1984; Hevner, 1935; Kastner & Crowder, 1990; Parncutt, 2014). If this is indeed the case, we therefore expect major cadences to be perceived as happier than minor cadences. Cadences often use a mixture of major and minor chords, such as a half cadence in minor ending on the dominant in major.

Another factor that has been found to play a role in emotional ratings of musical stimuli is average pitch height. Contrasting results have been reported on the effects of pitch height on both arousal and valence ratings. In studies by Lahdelma and Eerola (2016) and Parncutt (2014), it was suggested that pitch height affects arousal, rather than valence, as music with a higher average pitch generally contains more energy. As Parncutt (2014) points out, music in minor keys that are played in a high register can still be perceived as sad. The relation between average pitch and musical affect appears to be linked to speech-related affect, with sad speech showing an overall lower pitch and smaller pitch variation (Huron, 2008). In a study comparing speech and music excerpts, Ilie and Thompson (2006) reported that pitch height had an opposite effect for music and speech. Higher valence ratings were given to high-pitch speech excerpts, compared to their lower counterparts, but the opposite was found for the music excerpts. In other studies, pitch height was found to have a positive effect on valence and pleasantness ratings of Western diatonic chords (Huron, 2008; Huron & Davis, 2012; Temperley & Tan, 2013) and microtonal chords (Friedman et al., 2018; Smit et al., 2019). Taken together, these studies clearly indicate that there is a relationship between pitch height and valence and arousal, although the current findings are conflicting. Here, we aim to shed further light on the effect of average pitch height on perceived arousal and valence.

The aim of the present experiment was to examine perceived emotions, evaluated by arousal and valence ratings, of four cadence types. For the purpose of the current experiment, we defined cadences as chord progressions of four chords, of which the final two chords consist of a common cadential finish (e.g. authentic). The cadence types tested are authentic, plagal, half, and deceptive. We tested the effect of cadence type, mode (major or minor), style (triad or tetrad), average pitch, and the mode of the final chord on emotional responses. For this, we used a two-dimensional emotion model, which measures emotion perception on the two dimensions of arousal and valence (Russell, 1980). The two-dimensional emotion model has been validated in multiple music emotion studies, (e.g. Egermann & McAdams, 2013; Egermann et al., 2009; Grewe et al., 2007; Nagel et al., 2007; Schubert, 1999, 2001). In general, the following hypotheses were generated based on the prior discussed literature. The hypotheses for *Cadence type* are exploratory, as previous research does not allow to generate specific hypotheses regarding expected arousal and valence ratings. For *Mode*, it was hypothesized that minor would be lowest in valence and in arousal, and that the final chord being minor would be lower in arousal and valence than a final chord in major (Fang et al., 2017; Juslin & Västfjäll, 2008; Lahdelma & Eerola, 2016; Parncutt, 2014). Consonance was found to be strongly negatively correlated to energy and positively correlated to valence (Lahdelma & Eerola, 2016). We therefore expect by adding a tetrad in a cadence, and thereby introducing an additional dissonance, this might affect the cadence's perceived arousal and valence. For *Style*, we therefore predict cadences including a tetrad to receive lower valence and higher arousal ratings. Higher *Average pitch* was expected to lead to higher valence and higher arousal ratings (Lahdelma & Eerola, 2016; Parncutt, 2014; Smit et al., 2019).

Methods

Participants

Forty participants from the student population at Heinrich-Heine-University, Germany took part in this experiment (*mean age* $= 23$ years, $SD = 5.63$, 3 male). Participation was reimbursed with course credit. We asked participants to report years of musical training (*mean* $= 3.4$ years, $SD = 4.31$), however, this factor did not explain a meaningful proportion of the variance and was thus dropped as a factor in the models. Written informed consent was obtained from all participants prior to the start of the experiment, and the study received ethical approval by the ethics committee of the Medical Department of the Heinrich-Heine-University in Düsseldorf (no: 4044).

Stimuli

Authentic Cadence. The authentic cadence has chords whose roots move from the dominant (fifth scale position) to the tonic (first scale position), resulting in the harmonic progression V – I or V – i. This cadence is used to contribute to the tonality of a piece (or a section within a piece). The authentic cadence is usually considered to be a very stable and resolved cadence (Weiser, 1990). For this study, we used the *perfect* authentic cadence, meaning that the tonic is the highest note in the final chord and both chords are in root position. An *imperfect* cadence ends with the fifth or the third on top, or the chords are not in root position. Often, a seventh is added to the dominant in an authentic cadence to create a stronger effect of closure.

Plagal Cadence. The plagal cadence has chords in which roots move from the subdominant fourth scale degree (IV) to the first (I). The plagal cadence is also considered to be stable and resolved, but less strong than the authentic cadence (Weiser, 1990). This cadence is also known as the "amen cadence", considering its frequent setting to the word "amen" in hymns (Terry, 2016).

Half Cadence. The half cadence moves from any chord (often the tonic (I)) to the dominant (V). This unresolved ending often results in the perception of instability.

Deceptive Cadence. Another unstable cadence is the deceptive cadence. Its most common appearance is the progression from the dominant (V) to a non-tonic harmony, such as the sixth (vi): "the deceptive cadence leaves harmonic closure somewhat open [. . .]" (Sears, 2016, p. 53).

Important to note is that the chord progressions tested in this experiment were designed using a pop/rock style, meaning the use of piano timbre; small voice-leadings between chords; right hand playing all three chord degrees (root, third, and fifth) in close position; left hand playing the chord's root, usually doubled in octaves; including parallel and hidden fifths and octaves between left and right hand. We chose this approach as the majority of our participants are more familiar with this type of music than with classical music. All cadence types were presented in two versions, either with ordinary triads only or with the inclusion of one tetrad, leading to a total of 16 different cadences. As one of the aims of the experiment is to compare triads and tetrads in a cadence, we have added the same extension chord (a major

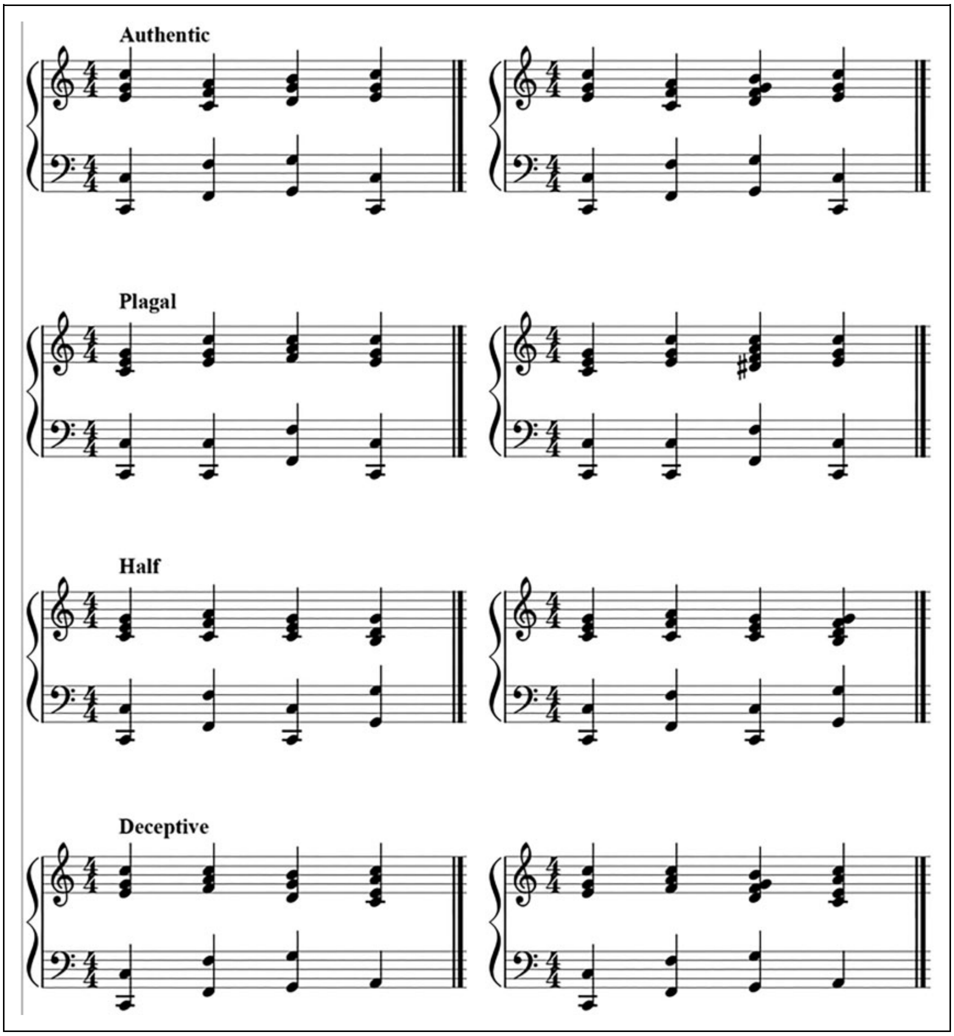

Figure 1. Major cadences. The left column are the cadences with triads only, the right column are those including tetrads.

triad with a minor seventh) in the tetrad cadences. An overview of the cadences used for this experiment is presented in Figures 1 and 2.

Average pitch height was calculated as the mean of all the musical pitches in a given cadence. To investigate the potential effect of pitch height, disambiguated from mode, the four trials for each factor combination were transposed. Specifically, each trial was allocated to one of four pitch regions (upwards transposition of 0–2, 3–5, 6–8, or 9–11 semitones (relative to the notations in Figures 1 and 2). Every cadence variant had a total of four trials, which were assigned to these four fixed pitch regions. However, a pitch from within those four regions was selected randomly. In this way, it was assured that trials were more or less evenly spaced over the octave, even with the reduced number of trials (4 per cadence).

Materials

Stimuli were generated and presented in Max/MSP 7 (Cycling '74) using the default AudioUnit DLS synthesizer on a Macintosh laptop, piano timbre and headphones (AKG Pro Audio K77). Each of the four cadence types (authentic, plagal, half, and deceptive) was presented four times for each factor combination of mode (major, minor) and style (triad, tetrad). We controlled for tempo; all cadences were played at 133 bpm for a quarter note at and at a constant MIDI key velocity of 80. Trials were presented in random order. The experiment took about 15 minutes to complete.

Procedure

After providing informed consent, participants were seated in front of a computer and all instructions were administered digitally. Participants filled out a demographic questionnaire. Afterwards, they were instructed to rate arousal and valence on a two-dimensional visual interface. Arousal was mapped to the vertical axis, labelled "High" at the top, and "Low" at the bottom. Valence was mapped to the horizontal axis, labelled "Positive" at the right, and "Negative" at the left. Both axes had a resolution of 300 points and intersected one another in the center (see Figure 3).

Figure 2. Minor cadences. The left column are the cadences with triads only, the right column are those including tetrads.

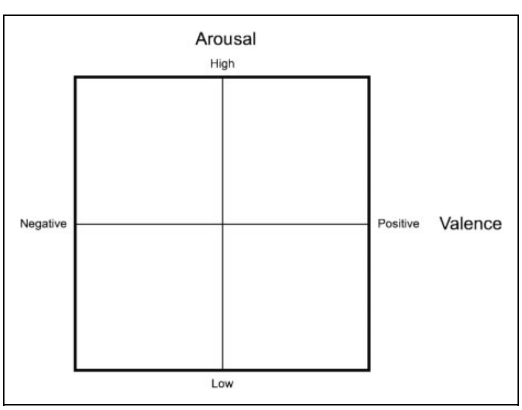

Figure 3. Screenshot of the response interface.

Participants were told to click towards the top of the interface if they perceived a chord progression as high in arousal (energy) and towards the bottom if they perceived the progression as low in arousal (energy). Additionally, if they perceived the progression as having a positively valenced emotion, they were instructed to click on the right side and on the left side for a negatively valenced emotion. Arousal and valence were described to participants by the following examples: a sad and depressed cadence might be low on arousal and negative in valence. A happy and exciting cadence might be high on arousal and positive in valence. Participants were asked if the instructions were clear and understood prior to proceeding to the experiment.

After each cadence, participants provided their arousal and valence judgments and the next cadence would play. To ensure a balanced design, each participant listened to 16 cadences of each of the four cadence types (total of 64 trials). Half of these 16 cadences were in major and half in minor mode. Half of the cadences within the major and minor modes were played as ordinary triads, and the other half were tetrads. As a result, there were four trials for each *Cadence type* (authentic, plagal, half, and deceptive) × *Mode* (major, minor) × *Style* (triads, tetrads) combination.

The present data collection was part of a large ongoing collaboration between Western Sydney University, Australia; Heinrich-Heine-University, Germany; and École Polytechnique Fédérale de Lausanne, Switzerland. All participants also performed another music perception task prior to participating, which will be reported elsewhere. As we are interested in affective responses, reducing fatigue in participants is important, therefore the experiment was chosen to be relatively short (around 15 minutes). However, the experiment is still sufficiently powered to detect small effects, as shown later by the model's results.

Statistical Methods

Bayesian Regression

This study used a multilevel Bayesian regression model to study the effects of the predictors of *Cadence type*, *Mode*, *Style*, and *Average pitch* on arousal and valence ratings. The results were modeled and analyzed in the statistical program R (R Core Team, 2014) in combination with the brms packages using Stan (Bürkner, 2017, 2018; Gelman et al., 2015). For an overview of the advantages of using a Bayesian statistical paradigm and the details of the main characteristics of Bayesian modelling, see Smit et al. (2019). We used a weakly informative prior (Gelman et al., 2014, 2015) with a Student's *t*-distribution with 3 degrees of freedom, a mean of 0, and a SD of 2.5 in order to reflect the parameters' level of certainty prior to data analysis (Van de Schoot et al., 2014). Continuous variables (arousal and valence responses) were standardized to have their mean at 0 and a SD of 1. Other predictors were turned into factors: *Cadence type* references to the authentic cadence, *Mode* to major, *Style* to triads, and *Final chord* to major. The variable *Final chord* determines whether the final chord of the cadence was major or minor and this was included in order to find out whether arousal and valence ratings were affected by the mode of the final chord. There is a possibility that participants' ratings are mainly based on the final chord of a cadence, rather than the cadence as a whole. This has been investigated by Tillmann and Marmel (2013), who examined tonal expectations and processing speed of chord sequences and showed that listeners are able to perceive differences in the tonal stability between chords regardless of their position within the sequence.

Therefore, if a minor cadence ends on a major chord and participants base their ratings mainly on the final chord of a chord progression, this would highly influence the results. As found in Smit et al. (2019), average pitch is a strong factor contributing to valence ratings of chords, therefore we also included the average pitch as a possible confounding factor in the models.

All variables are also included as random effects in the models to account for variability between participants, as well as a random intercept for trial number. Approximate leave-one-out cross validation (LOO) was performed in order to find the model that best fitted our data (Bürkner, 2017, 2018; R Core Team, 2014), leading to the following models:

$$\begin{aligned}\text{Arousal} &\sim \text{Cadence type} + \text{Mode} + \text{Style}\\ &+ \text{Final chord} + \text{Average pitch} + (\text{Cadence Type}\\ &+ \text{Mode} + \text{Style} + \text{Final chord}\\ &+ \text{Average pitch} \mid \text{Participant}) + (1|\text{Trial})\end{aligned}$$

$$\begin{aligned}\text{Valence} &\sim \text{Cadence type} + \text{Mode} + \text{Style}\\ &+ \text{Final chord} + \text{Average pitch} + (\text{Cadence Type}\\ &+ \text{Mode} + \text{Style} + \text{Final chord}\\ &+ \text{Average pitch} \mid \text{Participant}) + (1|\text{Trial})\end{aligned}$$

These interaction-free models for arousal and valence are reported in the results section. With regard to the number of predictors compared to the number of observations (64 per participant), Bayesian regression models are resistant to overfitting through the use of weakly informative priors and because they assess evidence from posterior distributions rather than single-point maximum likelihoods.

From the regression models, we can calculate *evidence ratios*, which are used to qualify evidence for directional hypothesis testing. Evidence ratios can be defined as probability ratios (odds) in favor of directional hypotheses (Smit et al., 2019). Evidence for the tested hypotheses will be qualified by the guidelines proposed by Jeffreys (1998) as cited by Kruschke (2018):

1. Evidence ratios of 3–10 are "moderate" evidence
2. Evidence ratios of 10–30 are "strong" evidence
3. Evidence ratios above 30 are "very strong" evidence

For reference, an evidence ratio of 19 roughly corresponds to an alpha of .05 in null hypothesis significance testing (Milne & Herff, in press). However, important to note is that, the estimated effects are all shrunk towards zero (regularized) through the use of a weakly informative prior centered at zero. In essence, this means that an evidence ratio of 19 (given a weakly informative prior) is analogous to a *p*-value *less* than 0.05, because the regularization helps to protect against false positives in noisy data.

Results

Arousal Model

The model output for arousal ratings is presented in Figure 4, which shows the 95% credibility intervals for the effects of the predictors of *Cadence type*, *Mode*, *Style*, *Average pitch*, and *Final chord.*

For the arousal model, the following hypotheses were tested. The strength of the evidence is presented in parentheses.

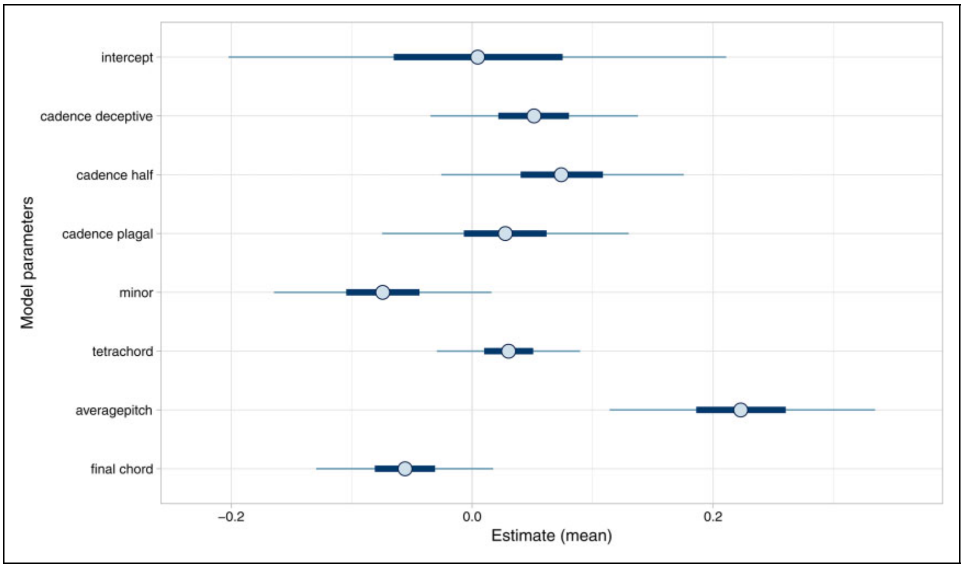

Figure 4. Estimated predictor coefficients and 95% Bayesian credibility intervals of the model predicting arousal ratings. The dark blue line shows the 50% interval; the light blue line shows the 95% interval.

Table 1. Hypothesis testing for the arousal model.

Hypothesis	Estimate	Est. Error	CI. Lower	CI. Upper	Evid. Ratio	Star
Half cadence > 0	0.07	0.05	−0.01	Inf	12.93	*
Deceptive cadence > 0	0.05	0.04	−0.02	Inf	7.34	
Plagal cadence > 0	0.03	0.05	−0.06	Inf	2.40	
Tetrads > 0	0.03	0.03	−0.02	Inf	5.39	
Minor < 0	−0.07	0.05	−Inf	0.00	18.02	*
Average pitch > 0	0.22	0.06	0.13	Inf	11,999.00	**
Final chord minor < 0	−0.06	0.04	−Inf	0.01	13.56	*

Note. Estimate = mean of the effect's posterior distribution. Estimate error = standard deviation of the posterior distribution. CI lower and CI upper are two-sided 95% credibility intervals. Evidence ratio = the posterior probability under the hypothesis against its alternative. * = evidence ratio is between 10-30 ("strong" evidence). ** = evidence ratio larger than 30 ("very strong" evidence).

1. The half cadence is more arousing than the authentic cadence (strong evidence)
2. The deceptive cadence is more arousing than the authentic cadence (moderate evidence)
3. The plagal cadence is more arousing than the authentic cadence (no evidence)
4. Cadences in minor are less arousing than cadences in major (strong evidence)
5. Cadences with tetrads are more arousing than triads (moderate evidence)
6. High average pitch is more arousing than low average pitch (very strong evidence)
7. If the final chord is minor, this is less arousing than if the final chord is major (strong evidence)

An overview of the hypotheses results is presented in Table 1.

Valence Model

The model output for valence ratings is presented in Figure 5, which shows the 95% credibility intervals for the effects of the predictors of *Cadence type*, *Mode*, *Style*, *Average pitch*, and *Final chord*.

The hypotheses tested for valence are presented below. The strength of the evidence is presented in parentheses.

1. The half cadence is lower in valence than the authentic cadence (no evidence)
2. The deceptive cadence is lower in valence than the authentic cadence (no evidence)
3. The plagal cadence is lower in valence than the authentic cadence (very strong evidence)
4. Cadences in minor are lower in valence than cadences in major (very strong evidence)
5. Cadences with tetrads are lower in valence than triads (very strong evidence)
6. High average pitch is higher in valence than low average pitch (very strong evidence)
7. If the final chord is minor, this will lead to lower valence than if the final chord is major (very strong evidence)

An overview of these results is presented in Table 2.

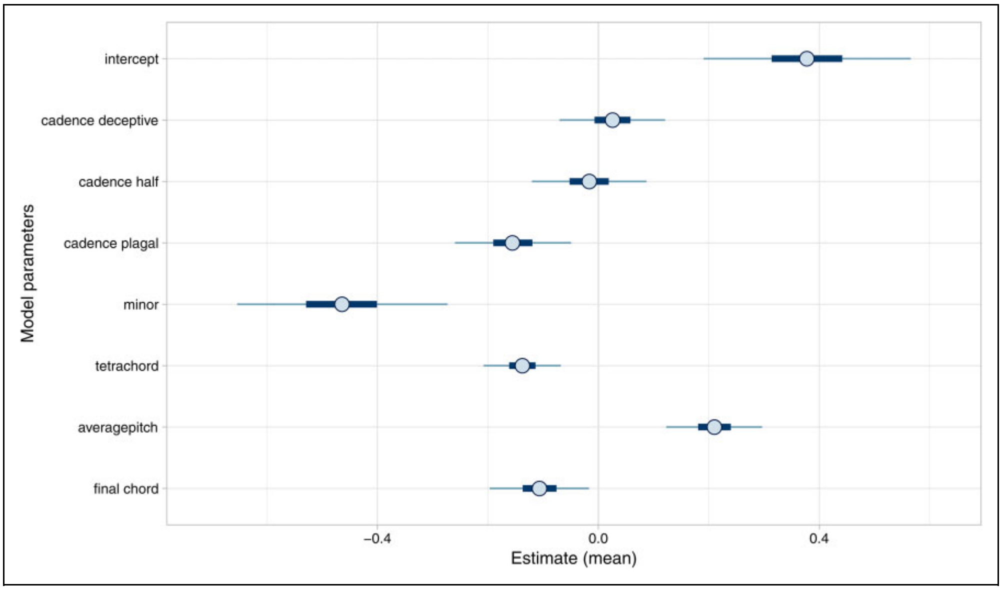

Figure 5. Estimated predictor coefficients and 95% Bayesian credibility intervals of the model predicting arousal ratings. The dark blue line shows the 50% interval; the light blue line shows the 95% interval.

Table 2. Hypothesis testing for the valence model.

Hypothesis	Estimate	Est. Error	CI. Lower	CI. Upper	Evid. Ratio	Star
Half cadence < 0	−0.02	0.05	−Inf	0.07	1.66	
Deceptive cadence < 0	0.03	0.05	−Inf	0.11	0.42	
Plagal cadence < 0	−0.15	0.05	−Inf	−0.06	460.54	**
Tetrads < 0	−0.14	0.04	−Inf	−0.08	8,999.00	**
Minor < 0	−0.46	0.10	−Inf	−0.31	17,999.00	**
Average pitch > 0	0.21	0.04	0.14	Inf	>35,999.00	**
Final chord minor < 0	−0.11	0.05	−Inf	−0.03	91.78	**

Note. Estimate = mean of the effect's posterior distribution. Estimate error = standard deviation of the posterior distribution. CI lower and CI upper are two-sided 95% credibility intervals. Evidence ratio = the posterior probability under the hypothesis against its alternative. * = evidence ratio is between 10-30 ("strong" evidence). ** = evidence ratio larger than 30 ("very strong" evidence).

General Discussion

This study investigated arousal and valence perception of four cadence types common in Western classical music. Apart from looking into the cadence types themselves, we were also interested in the effects of the cadences being in a major and minor mode, and the presence of tetrads, which often occur in cadences (namely the dominant 7th), and the mode of the final chord. Average pitch was included as an extra dependent variable, as this has been shown previously to have a strong effect on affective ratings of musical elements (Huron, 2008; Smit et al., 2019).

Cadence Types

We investigated whether the four different cadence types would show differences in arousal and valence ratings. Concerning the arousal ratings, it was found that both the half and the deceptive cadences are more arousing than the authentic cadence, supported by strong and moderate evidence, respectively, but with very small effect sizes. These findings are in line with the general nature of the half and the deceptive cadence as they both have an element of unpredictability. By ending on the fifth degree, instead of the first degree, the unfinished nature of the half cadence is perceptually reflected in higher arousal ratings, likely due to violation of musical expectancy. Similarly, by ending on the sixth degree with a minor chord, instead of the expected first degree with a major chord, the higher arousal ratings for the deceptive cadence support the unexpectedness of the cadence. As supported by a multitude of studies, unexpected events have an element of surprise, leading to tension (Gingras et al., 2016) and to higher arousal than expected events (Egermann et al., 2013; Koelsch et al., 2008; Sauve et al., 2018; Steinbeis et al., 2006). One of the possible mechanisms underlying spikes in arousal for unpredictable musical events, such as the half cadence, is the brain stem reflex (Juslin & Västfjäll, 2008), which suggests that specific acoustical features of a musical event are signaled by the brain stem to be of importance and therefore inducing higher arousal. Musical events that can trigger this response in the early stages of auditory processing are for example, loud, sudden, or dissonant events (Juslin & Västfjäll, 2008). It is possible that higher arousal ratings for unexpected and dissonant events, such as the half cadence ending on a tetrad, could be related to a stronger brain stem reflex.

For the valence ratings, we found very strong evidence that the plagal cadence was rated lower than the authentic cadence. These results are in line with theory that is, in this case, lesser known. The term "plagal cadence" as we currently know it, has only been used since the eighteenth century (Terry, 2016). The cadence existed prior under various names, and was even referred to as the "minor" cadence in the German-Latin tradition by Felix Diergarten (Terry, 2016, p. 32), and described by Bononcini (1673) in his *Musico Prattico* as having a sad nature and relating to the grave (Terry, 2016, p. 54). A thorough description of the history of the plagal cadence can be found in Terry (2016).

Apart from support through musicological theory, these results can also be discussed in light of some psychological mechanisms. As discussed earlier, musical expectancy theory already suggests that musical elements different in *syntactical* structure, have differing levels of predictability and can lead to different emotional responses in listeners. It is suggested that, in this case, music functions similarly to language, as both follow a set of rules. Listeners create expectations about when a musical element follows the rules and when it is "incorrect", leading to a corresponding emotional response. Our experience with a particular musical style (in this Western musical harmony) therefore impacts how we perceive musical structures that are more expected (such as an authentic cadence) and those that are unexpected (such as a deceptive cadence).

Therefore, it is somewhat surprising that we found lower valence ratings for plagal cadences than for the less predictable half and deceptive cadences. As discussed earlier, musical events that are unexpected can lead to a higher valence response (Huron, 2006), as well as events that have high predictability. It is possible that the plagal cadence is perceived as being predictable, due to its stable nature and ending on a first-degree major chord, yet not sufficiently predictable to elicit a high valence response. This particular result provides evidence that, whilst predictability and valence are related, any effect of predictability is nonlinear. Also, although it is likely that predictability plays an important role, many other features and mechanisms are likely involved as well. To further our understanding of other contributors to valence and their possible psychological mechanisms, we suggest future studies that look at corpora, as well as psychoacoustic properties.

Mode

With regard to mode, it was also tested whether the cadence being in major or minor mode would have an effect on arousal and valence ratings, as minor is often associated with sadness (e.g. Kastner & Crowder, 1990; Crowder, 1984; Hevner, 1935; Parncutt, 2014). We found strong evidence for minor cadences being very slightly less arousing ($\beta_{\text{Minor}} = -0.07$, $\text{Odds}(\beta_{\text{Minor}} < 0) = 18.02$) and very strong evidence for substantially lower valence ($\beta_{\text{Minor}} = -0.46$, $\text{Odds}(\beta_{\text{Minor}} < 0) = 17999.00$). The latter finding confirms previous literature linking higher valence with the major mode (e.g. Fang et al., 2017; Juslin & Västfjäll, 2008; Lahdelma & Eerola, 2016; Parncutt, 2014), as well as with common knowledge amongst Western musicians.

Important to note is that these results might be limited to populations enculturated to Western musical systems. For example, in a study testing Chinese participants on Western music, Fang et al. (2017) found that the major mode induced higher arousal than the minor mode, whereas the opposite was found by van der Zwaag et al. (2011) who tested participants in the Netherlands. Furthermore, ethnomusicological data shows that the same music can be used to express both sadness and happiness (Baraldi, 2009).

Furthermore, we hypothesized that the mode of the final chord would have an effect on the arousal and valence ratings. Indeed, we found strong evidence that the cadence was perceived as less arousing when the final chord was minor and very strong evidence that those cadences are lower in valence as well. An implication of this is that listeners might have a bias in weighting the last chord disproportionately when assessing affect of chord progressions.

Triads and Tetrads

Another interesting finding concerns the effect of the tetrads on valence/arousal ratings. Two possible theories were proposed for the effect of a tetrad in the cadence: 1) it would have a significant impact on the perception of valence/arousal, leading to lower ratings 2) the dissonant chord could be regarded as an expendable embellishment (Neuwirth & Bergé, 2015). We found moderate evidence to support the idea that cadences with a tetrad receive higher arousal ratings, but very strong evidence to support that these cadences receive lower valence ratings. The results from this study therefore suggest that having a seventh added to a major chord does impact the overall arousal and valence perception of a cadence. Important to note is that we tested only two tetrads, and therefore we cannot be conclusive about the impact of these results.

Average Pitch

In previous experiments, average pitch height has been shown to have a strong effect on valence and consonance ratings of microtonal chords (Smit et al., 2019) and Western diatonic chords and melodies (Huron, 2008; Huron & Davis, 2012; Temperley & Tan, 2013). This finding is replicated in the current experiment with both arousal and valence ratings of cadence types. Consistent with the literature, we found very strong evidence which supports that a higher average pitch height results in higher perceived arousal, and in higher valence. Noticeably, average pitch seems to strongly impact perceived affect of music in general, and has a stronger impact than other psychoacoustic features (such as harmonicity, roughness, and spectral entropy) (Smit et al., 2019). The effect of average pitch on perceived affect in Western diatonic music and microtonal music is suggestive of a bottom-up perceptual bias towards pitch (e.g. Smit et al., 2019), and is also supported by affect-related pitch prosody in speech (Huron, 2008). Overall, the consistent role of average pitch in music perception studies shows the importance of accounting for it when designing and analyzing music perception experiments (Eerola et al., 2001).

For composers and musicians, these results give interesting food for thought on how a single acoustic component can have a large impact on perception, regardless of other musical factors. Interestingly, the effects of the tested factors are in general much stronger for valence than for arousal, with exception of average pitch. The features tested here are all pitch or tonality based. Other acoustic features have been found to have a greater effect on arousal, such as acoustic intensity (loudness) (Bailes & Dean, 2012; Dean et al., 2011) and tempo (Droit-Volet et al., 2013), all held constant in the current experiment. Future studies which take these parameters into account should be undertaken.

Limitations

The generalizability of this study is subject to several limitations. First of all, although we did not observe strong evidence that cadence perception regarding arousal and valence is influenced by musical expertise, we used a very crude measure of musical experience. Future research should investigate this aspect with a more sophisticated measure such as the Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2014). It would also be interesting to compare non-musicians with professional musicians to see whether musical expertise has an influence on perceived emotion.

Also, the stimuli were limited to a few chord progressions. Each of these cadence types can take on several forms by themselves, e.g. an authentic major cadence can be preceded by different chords, as long as the V – I structure is acknowledged. As we decided to adhere to general musical theory, with the notable exception of counterpoint rules, the minor cadences included major chords as well. This might have had an influence on the ratings, especially when a minor cadence is concluded with a major chord. Another limitation is that we only tested for one type of tetrad per cadence. In order to draw stronger conclusions about the effect of an extra note in the cadence, more studies would have to be conducted with a larger sample of possible tetrads. Lastly, given the short length of the trials and the use of transposition, listeners might not have been able to adjust to the new key in-between trials. We therefore recommend implementing short inter-stimulus intervals of around 10 seconds (Woolhouse et al., 2016), or short white noise bursts (Butler & Ward, 1988) in between trials in order to avoid trial sequence effects for future studies.

Conclusion

The current study examined arousal and valence perception of four common cadence types with manipulations in *Cadence type*, *Mode*, *Style*, *Average pitch*, and *Final chord*. Participants were asked to listen to short musical cadences and rate the arousal and valence on a two-dimensional emotion model. We found that the mode of a cadence (major or minor) had a strong influence on both the valence ratings, and on arousal. A strong effect of pitch height was also found, confirming prior research stating that a higher average pitch leads to higher arousal and valence ratings. It was also found that half and deceptive cadences are more arousing than the authentic cadence and that the plagal cadence was lower in valence than the authentic cadence. Finally, the results support the idea that an additive dissonant note by including a tetrad in one of the cadential chords impacts the overall arousal and valence levels of a cadence, and that a cadence is perceived as less arousing and lower in valence when the final chord is minor. With the exception of average pitch, these effects are all stronger on valence than on arousal ratings. However, more research is needed as only a limited number of cadences were tested.

The insights gained from this study may be of interest for music performers, composers, automated compositions systems as well as music theorists, as knowledge of how specific musical structures impact perceived emotion in music is important for performance practice. Also, music-based therapies can benefit from a research-based approach to perceived emotions of specific musical structures. Further research could look into the link between perceived emotions and auditory expectation of cadences, with special regard to the perception of closure and the psychological mechanisms involved.

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ES, FD, and SH conceived the study and ES researched the literature. ES, FD, and SH were involved in the study design. SH and NS were involved in participant recruitment. ES, FD, SH and AM were involved in data analysis. ES wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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