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Pitch Height and Mode Have Asymmetrical Effects on the Perception of Mixed Emotions in Major and Minor Seventh Chords

Noah R. Bongiovanni[1], T. M. Vanessa Chan[2], Stephen C. Van Hedger[3, 4], Colin Findley[5], and Berthold Hoeckner[1]
[1] Department of Music, University of Notre Dame
[2] Department of Psychology, University of Notre Dame
[3] Department of Psychology, Huron University College at Western
[4] Department of Psychology and Western Institute for Neuroscience, University of Western Ontario
[5] School of Computing, DePaul University

Music has long been recognized for evoking emotion from the listener. However, in musical chords, the relationship between mode and emotion, beyond basic associations of “major”–“happy” and “minor”–“sad” in triads, remains poorly understood. The present study investigates how mode contributes to the perception of mixed emotions in major and minor seventh chords, containing a triad from both modes. In Experiment 1, participants identified the emotion they perceived (happy, sad, or bittersweet) in response to a selection of major and minor triads and seventh chords. To observe the effect of changing mode salience, participants heard the same seventh chords whose root or seventh was lowered in volume. In Experiment 2, participants responded to seventh chords with roots or sevenths that were quieted in multiple increments. Experiment 3 expanded the paradigm by asking participants to judge the emotion of each chord on a sliding scale and introduced a second mixed-emotion choice (nostalgic). Overall, participants were more likely to report a seventh chord as bittersweet (Experiments 1 and 2) or happy (Experiments 2) but not sad. The likelihood of a seventh chord being rated as “happy” increased with highlighting the major triad present in a minor seventh chord through quieting the chordal root, but the likelihood of a seventh chord being rated as “sad” increased with lowering the volume of a chordal seventh, regardless of mode. The effect of pitch height on emotional perception is considered, and implications for the general understanding of complex emotional categories are discussed.

Keywords: auditory perception, emotion, categorization, music, mode

Supplemental materials: https://doi.org/10.1037/aca0000705.supp

The capacity to express emotions has long been considered a central characteristic of music (e.g., Egermann et al., 2015; Koelsch, 2014; Webster & Weir, 2005; Zentner et al., 2008). Cooke (1959) famously described music as a “language of emotions,” suggesting that specific types of music can communicate emotional meaning. While prior empirical studies have explored how musical elements such as tempo or articulation can create emotional meaning (Bresin & Friberg, 2011; Gomez & Danuser, 2007; Juslin & Lindström, 2010), Lahdelma and Eerola (2016a) investigated the emotional meaning perceived in chords commonly used in Western music. A chord, which is made up of three or more simultaneously sounding pitches (Parncutt, 1989), is perceived as a whole acoustically by the listener (Bregman, 1990) and constitutes the basic element contributing to a vocabulary of “vertical harmony,” as distinguished from the harmonic progressions of “horizontal harmony” (Cohn et al., 2001). Lahdelma and Eerola (2016a) found significant variations in emotion perception for different chords; they also observed that chord inversion and timbre also had a significant effect on their participants’ perception of emotion. Perhaps unsurprisingly, major and minor triads elicited the strongest differential in participant responses of perceived emotion: Major triads received high mean ratings for “happiness” and low mean ratings for “melancholy,” whereas minor triads received inverse ratings. Their findings are supported by other work; for example, Bakker and Martin (2015) demonstrated an association between “major–happy” and “minor–sad” pairings as evidenced by early neuronal processing speed even among participants with no formal musical training. These results support the understanding that differences between the major mode and minor mode, including the robust association with happiness and sadness, respectively (e.g., Gagnon & Peretz, 2003), has been foundational to Western tonal music, though these valences may differ in other cultures (Lahdelma et al., 2021).

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Noah R. Bongiovanni https://orcid.org/0000-0002-1615-5352
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Correspondence concerning this article should be addressed to Berthold Hoeckner, Department of Music, University of Notre Dame, 502 O’Neill Hall of Music and Sacred Music, Notre Dame, IN 46556, United States. Email: bhoeckne@nd.edu

However, Lahdelma and Eerola (2016a) did not observe the same clear contrast in ratings for major and minor seventh chords; these chords received a less distinct separation between mean happiness and melancholy ratings when compared to the major and minor triads. This finding suggests that the emotion perceived in these types of chords does not neatly fit either category. Furthermore, the ratings of major and minor triads and sevenths chords differed for perceived nostalgia—a mixed emotion that has been described as "both the enjoyment of remembering the past and the painful knowledge that the past is irretrievable" also often referred to as "bittersweet" (Garrido, 2017, p. 194). Although perceived nostalgia was statistically equivalent for the minor triad as well as both the major and minor seventh chords, major triads alone had a lower rate of perceived nostalgia. Examining how nostalgia ratings compare to primary ratings of happiness and melancholy, the researchers observed that both types of seventh chords were also rated higher for perceived melancholy than for perceived happiness, suggesting that the perceived emotions in seventh chords are complex but have a slightly stronger tendency toward being perceived as sad.

The association between major and minor seventh chords and mixed emotions, such as nostalgia, could have several foundations. First, it is likely that these associations are at least partly learned. The use of major and minor seventh chords by composers of Western music (e.g., in film scores) are frequently interpreted by listeners as conveying complex emotions, including nostalgia and bittersweetness (for a more detailed discussion, see Juslin, 2019; Lahdelma & Eerola, 2015). However, the role of learned associations does not necessarily suggest that associations between major and minor seventh chords with nostalgia are entirely arbitrary. In the next several paragraphs, foundations for these associations are discussed in greater detail.

A second possibility for how major and minor seventh chords can convey mixed emotions has to do with the simultaneous presence of major and minor triads within these chords. Although an extensive body of research has found associations between happiness and sadness with major and minor triads, respectively (Crowder, 1984; Gagnon & Peretz, 2003; Gerardi & Gerken, 1995; Peretz, 1998; Scherer & Oshinsky, 1977), it is possible that the perception of a mixed emotion in major and minor seventh chords results from a change in single mode salience, that is, whether these chords might result in listeners hearing both modes and hence perceiving multiple emotions at the same time. Major and minor seventh chords in music theory are typically described as a major or minor triad with an added major seventh or minor seventh (as measured from the root), or as a third stacked on top of a triad (as measured from the fifth) (Benward & Saker, 2003), or as a triad stacked on top of a third. Moreover, one can also conceive of the major and minor seventh chords as interlocking major and minor (or minor and major) triads sharing a third (see Figure 1). This construction may therefore allow listeners to perceive and appreciate simultaneous representations of happiness and sadness within these chords, and thus be more likely to report these chords as conveying a mixed emotion, such as bittersweetness.

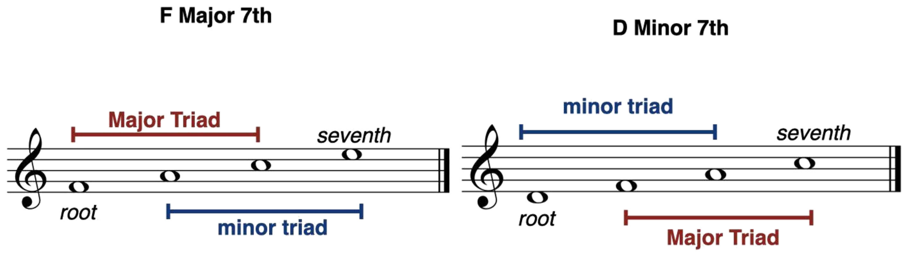
Although major and minor seventh chords might derive their mixed emotions from interlocking major and minor triads, this is not the only potential explanation for how these chords might convey a mixed emotional state. After all, major and minor triads themselves can be conceptualized as stacked major and minor thirds (i.e., a major triad in root position consists of a major third plus a minor third, and a minor triad in root position consists of minor third plus a major third). This theoretically opens up the possibility that these chords should also elicit perceptions of mixed emotion, particularly given the observed associations between major and minor thirds with happiness and sadness, respectively (e.g., Curtis & Bharucha, 2010; Oelmann & Laeng, 2009). Yet, as noted previously, major and minor triads generally have consistent associations with happiness and sadness in Western music (Bakker & Martin, 2015), which potentially suggests alternative mechanisms underlying these emotion associations.

Another potential mechanism that might underlie the mixed emotions of major and minor seventh chords is rooted in their psychoacoustic properties. Specifically, it is possible that major and minor seventh chords create a sense of dissonance (e.g., through increased psychoacoustic "roughness" and increased inharmonicity) from the added seventh that, when considered alongside the major or minor triad, contributes to a mixed emotional state, given the general unpleasantness of auditory roughness (e.g., Harrison & Pearce, 2020; Parncutt et al., 2019) and general pleasantness of major and minor triads, at least among those familiar with Western music (e.g., Lahdelma et al., 2021). Interestingly, this potential explanation would also suggest that the major seventh (which contains a greater sense of roughness and a greater degree of inharmonicity) might convey mixed emotions differently than the minor seventh chord.

The present set of experiments were designed to test whether major and minor seventh chords, which contain interlocking major and minor triads, and also contain mixed degrees of positive and negative valence from a psychoacoustic perspective, are more effective at conveying mixed emotional states compared to major and minor triads. If this were the case, music might provide an example for supporting the theory that positive and negative emotions are not bivariate but may function as distinct and separate dimensions that need not be experienced as oppositional but as working together (Cacioppo et al., 1999; Garrido, 2017; Rafaeli et al., 2007). We hypothesized that in major and minor triads, where the major and minor mode is salient, listeners, when given the choice between the emotions of happiness, sadness, or the mixed emotion of bittersweetness, would more likely select the corresponding single-valence emotion of happiness or sadness instead of bittersweetness. However, although the emotion perception of major and minor triads is straightforwardly dichotomous, this would be different for major and minor seventh chords. Specifically, we hypothesized that listeners, when presented with a forced choice between the three emotions for the major or minor seventh chord, would be less likely to select the single-valence emotion associated with the seventh chord's original triad and select instead the mixed emotion of bittersweetness. This hypothesis is based on earlier theoretical work (Cooke, 1959; Everett, 2008) as well as more recent empirical work (Lahdelma & Eerola, 2016a).

While the perception of mode categories in triads has been tested by gradually changing the pitch of the third from major to minor (Crowder, 1985; McMurray et al., 2008), we tested the effect of mode in major and minor seventh chords by gradually changing the volume of the root and the seventh (see Hall & Pastore, 1992 for a similar approach). We hypothesized that lowering the volume of the added seventh to raise mode salience of the root triad would boost listeners' choice of the corresponding single-valence emotion and depress mixed emotion choices. We expected that this effect would also show when lowering the volume of the root of the

Figure 1
Major and Minor Seventh Chord as a Combination of Triads



Note. The major triad notes are bracketed in red (dark gray), and the minor triad notes are bracketed in blue (light gray). The overlap between the brackets highlights the third that both triads share in common, respectively. Note that the upper triads are in the mode opposite of the nominal seventh chords. See the online article for the color version of this figure.

seventh chord, which would raise the mode salience of the upper triad (in the opposite mode) and thereby increase the likelihood of selecting the corresponding single-valence emotion. However, we recognized that this portion of experimentation might be affected by pitch height, which has been shown to influence emotion perception (see Crowder, 1985; Smit et al., 2019).

Experiment 1

Method

Participants

A total of 107 participants took part in the first experiment. Age was collected as an ordinal variable, with options of 18 to 24 years old ($n = 1$), 25 to 34 years old ($n = 19$), 35 to 44 years old ($n = 31$), 45 to 54 years old ($n = 40$), and 55 to 64 years old ($n = 10$), with $n =$ 6 not responding. Each participant was recruited through Prolific (https://www.prolific.com) (29 April 2023), an online recruitment platform which provides several screening criteria that can be applied to encourage effortful participation. We additionally used auditory attention checks in the experiment to confirm that participants were listening to the sounds (see Procedure section for details). Although Experiment 1 (and all subsequently reported experiments in this article) was conducted online, recent work has suggested that online data collection can yield comparable data quality to in-lab data collection (e.g., Eerola et al., 2021; Zhao et al., 2022). Criteria for participation in the experiment included being located in the United States, being between the ages of 30 and 60 years old, having a prior approval rating of at least 50% across prior Prolific experiments, speaking English as a first language, and having not participated in prior iterations of the multiexperiment study. To balance the data set, we further directed Prolific to invite an equal number of men and women to complete the experiment. Qualtrics survey results confirmed this effort was successful; among those willing to self-report, survey results show the balance between men and women was 42 to 45, with one participant selecting nonbinary. Because the experiment required a developed understanding of bittersweetness as a complex emotional category, we selected the age range to include only adults whom we posited had the lived experience to make evaluations where bittersweetness was the criterion. Participants were not specifically recruited on the basis of prior musical training; survey results show that 78% of respondents did not consider themselves to be musicians, and 62% had no experience playing a musical instrument or singing. Sample size was primarily determined by the availability of funding and the median time required to complete the study, to ensure that participants were compensated at a fair hourly rate. However, we also considered the sample size of Lahdelma and Eerola (2016a) as a reference. While their study recruited 269 participants, they also presented each participant with 14 different chord types, two timbers, and nine emotions to respond to on a 5-point Likert scale for each. Given the comparatively narrow scope of our single-timber, three-choice forced response paradigm, we feel that our sample size is adequately sized proportionally to comparable prior work.

Several participants ($n = 7$) completed the experiment, but failed to finish the follow-up questionnaire. Furthermore, some participants were rejected from preliminary analysis based on predetermined exclusion criteria (see Data Exclusion section). As such, reports on the demographics or other self-reported variables only refer to the subset of participants ($n = 92$) that were included in our data analysis and from which experimental and survey data were obtained. The protocol for the experiment was approved by the University of Western Ontario Research Ethics Board (Protocol 112574), and all participants received monetary compensation upon completion of the entire experiment, including the questionnaire.

Materials

This experiment was programmed using jsPsych Version 6.1 (de Leeuw, 2015). The programmed experiment was run using Pavlovia (Open Science Tools Limited: Nottingham, United Kingdom), a Gitlab server and repository for the online delivery of behavioral science experiments, and the follow-up questionnaire was administered with Qualtrics (Provo, Utah).

The musical chords presented to the participants for evaluation were synthesized in Logic Pro 10.7.8 (Apple: Cupertino, California) using the "Steinway Grand Piano" patch. The patch mimics the natural attack and decay of a real piano, which allows for a more organic-sounding Musical Instrument Digital Interface sample. The audio files were trimmed to 2000 ms in duration. Each chord sounded for a duration of 1000 ms; a 1000-ms period of silence was left after each chord to prevent clipping artifacts during the experiment. All chords were exported and preloaded to the experiment with a sampling rate of 44.1 kHz and 16-bit depth as lossless (.wav) audio files.

The musical chords in this experiment were constructed with each note on an individual track for the purposes of adjusting the relative volume of key notes. Seventh chords designated as "default" volume contained the four notes all at normal export volume (0 dB). Chords designated as having a "quiet root" or "quiet seventh" note contained a root or seventh lowered to −10 dB in volume, and the other three notes in the chord remained at normal volume. Triads designated as a seventh with "no root" or "no seventh" had only three notes, all at normal volume, with the specified note removed. Major seventh chords were constructed in B major (i.e., B, D#, F#, A#) and C major (C, E, G, B), and minor seventh chords were constructed on C minor (C, Eb, G, Bb) and D-flat minor (Db, Fb, Ab, Cb). The notes of these chords fall in a range of just above one octave (the "middle C" octave on a piano); this decision to keep all chords clustered around the same register was made to eliminate pitch height as a potential confounding factor. Specifically, the range of lowest notes across both modes spans only three half steps (B to Db), and the range of highest notes only two half steps (A# to B), such that the required changes in chord quality across the stimuli were not accompanied by a potentially distracting register shift. Triads were then built by removing either the chordal root or the chordal seventh. Thus, participants were asked to judge 20 different chord types—12 seventh chords (four at full volume, four with a quieted root, and four with a quieted seventh) and eight triads.

Before beginning the experiment, participants completed a short auditory calibration. The materials for the auditory calibration were taken from a recent online auditory study (Bongiovanni et al., 2023) A 5-s pink noise sample created in Adobe Audition was played between trials to clear auditory working memory. Pink noise (also referred to as 1/f noise) contains equal energy per octave of frequency. In contrast, white noise contains equal energy across all frequency levels, meaning white noise contains greater energy at higher frequencies.

Procedure

After recruitment on Prolific, participants were presented with a letter of information detailing the experiment. Upon providing their informed consent and providing their anonymized Prolific identification number, participants completed an auditory calibration check. The first portion of the calibration involved participants listening to a noise sample and adjusting their computer volume to a comfortable level. The second portion was a six-trial headphone check that presented participants with three tones per trial and asked them to identify which tone was quieter than the other two. The calibration, based on Woods et al. (2017), is designed such that the participant can only pass if wearing headphones as instructed. Participants earned a "passing" score if they answered at least five out of the six judgments correctly.

Following the auditory calibration, participants were given directions regarding the nature of the experiment. Participants were instructed that they would be judging a series of different musical sounds by assigning each chord an emotional rating of "happy," "sad," or "bittersweet" using the "H," "S," and "B" keys on their keyboards. Participants were told that they could only choose one emotion per sound and that they should select the one that best fits their judgment as promptly as possible. Then participants completed the main task, in which they completed two blocks of chord judgments. Within each block, participants judged all 20 chords in a randomized order, for a grand total of 40 analyzed trials. Participants saw the prompt, chose an emotion upon hearing the chord, and then heard a pink noise sample before beginning the next trial. As an attention check, once participants completed the first block of judgments (i.e., after the first set of 20 randomized trials), they encountered a blank screen and an audio voice command instructed them to press the "5" key to ensure they were paying attention. A second voice command asked them to press the "7" key. These attention checks were designed to ensure that participants had not muted their sound and were attending to their answers in an effortful manner. After completing the attention check, participants completed the second block of judgments.

Participants were then directed to complete the Qualtrics follow-up questionnaire. Survey questions collected demographic information, self-reported estimates of musical ability, instruments played, frequency of musical practice, and the amount participants listened to music for pleasure. The questionnaire also asked participants to share titles of songs that they considered bittersweet, as well as the reasoning behind their selection; however, this data was for exploratory purposes only and is not further analyzed in the present study. When the questionnaire was complete, participants received a Prolific completion code and were compensated for their time; the experiment had a median completion time of 13 min, and participants were paid $2.25 resulting in a mean hourly rate of $10.44.

Data Exclusion

We established two criteria for which participant data could be excluded from consideration during primary analysis. First, if participants completed only part of the experiment, their results were removed from the aggregate data set. However, as previously discussed, participants who completed the experiment but not the questionnaire were still included, as their data set was complete. Second, participants who failed the attention check at the halfway point of the experiment by scoring less than 100% correct were excluded from the analysis. Failing to answer the attention check correctly was interpreted as a lack of attentiveness to the experiment stimuli. Although performance on the initial headphone check was noted, participants were not excluded from analysis based on any sort of performance threshold.

Of the 107 total participants, two participants were excluded for not completing the entire experiment before exiting the server. An additional 13 participants failed the attention check and were omitted from consideration. This left 92 participants for consideration in our data analysis. Of the participants who met the criteria for inclusion, 61% passed the headphone check based on the Woods et al. (2017) threshold.

Data Analysis

All statistical tests were conducted using R, Version 4.2.1 (R Core Team, 2021). Based on the three-alternative forced-choice design of the task and the repeated measurements for each participant, we elected to use a mixed-effects multinomial logistic regression with the random effect of Participant, using package *mclogit* (Elff, 2022). Since we wanted to test the effect of manipulating various properties of the chords on the extent to which it is rated as representing emotion of mixed valence, we used the likelihood of naming a chord as bittersweet as the reference category. Thus, the regression is modeling the probability of a chord being labeled as happy or sad, relative to bittersweet.

Separate analyses were completed for the seventh chords and the triads. For the seventh chords, we modeled the fixed effects of chord quality (major seventh vs. minor seventh) and volume (default vs. quiet root vs. quiet seventh), as well as the interaction of chord quality and volume. Chord quality was contrast-coded (1 major/−1 minor), and volume was treatment coded with default as the reference condition.

For the triads, we modeled the variables of chord quality (major triad vs. minor triad) and chord type (whether the triad originated from a seventh chord by eliminating the root, or by eliminating the seventh), as well as the interaction of chord quality and chord type. Contrast coding was applied to both chord quality (1 major/−1 minor) and chord type (1 rootless/−1 seventhless).

Results

Seventh Chords

The results of the multinomial logistic regression are listed in Table 1. Overall, diverging effects of chord quality and volume were seen on the probability of chords being labeled as happy or sad, without any significant interactions. Though chord quality affected the likelihood of a chord being labeled as happy, it did not affect the likelihood of it being labeled as sad. Quieting the root also affected the likelihood of a chord being labeled as happy but not sad, and quieting the seventh showed opposite effects on the likelihood of a chord being labeled as happy or sad. The probability of selecting each emotion label for each chord is presented in Figure 2.

To assess how participants responded to the major and minor seventh chords without manipulation, we also completed an analysis with only the default volume chords, while maintaining chord quality as contrast-coded. This leaves the intercept as a representation of the base likelihood of a major or minor seventh chord being labeled as bittersweet as compared to either happy or sad. Unsurprisingly, these results are largely similar to that of the overall model; results are listed in Table S1 in the online supplemental materials.

Triads

The results of the multinomial logistic regression for the triads are listed in Table 2. Unlike with the major and minor seventh chords, triads were not more likely to be classified as bittersweet compared to happy or sad. Major triads and triads that came from removing the root of a major or minor seventh chord were both more likely to be rated as happy compared to bittersweet. Triads that came from removing the seventh of a major or minor seventh chord were more likely to be rated as sad, and this effect was stronger in major triads as indicated by the significant interaction term. The probability of selecting each emotion label for each triad is presented in Figure 3.

Discussion

In Experiment 1, we sought to characterize the elements of a major or minor seventh chord that give it its mixed valence by manipulating the extent to which the major or minor triad in a seventh chord was represented. Without these manipulations, we found that the perceived emotion in major and minor seventh chords are more likely to be bittersweet than the single-valence emotions of happy or sad. However, the greater likelihood of a minor seventh chord to be rated as happy than a major seventh chord suggests that in these seventh chords, the perceived emotion rating may not align, but elicit a rating of opposite valence than the emotion traditionally associated with the mode in the chord name. This finding of greater bittersweetness in major seventh chords might also relate to psychoacoustic properties, as major seventh chords contain greater degrees of auditory roughness—a generally unpleasant sensation—which could potentially convey a mixed emotional state more effectively (e.g., see Lahdelma & Eerola, 2015). We also observed asymmetrical effects with respect to how manipulating each chord changed the probability of labeling the chord as "happy" or "sad" relative to "bittersweet." Specifically, while quieting the root of a major or minor seventh chord made it more likely to be labeled "happy," and quieting the seventh of a major or minor seventh chord made the same result less likely, the probability of labeling a chord as "sad" relative to "bittersweet" was only increased by quieting the seventh. Interestingly, major seventh chords were generally less likely to be labeled as "happy" relative to minor seventh chords, whereas chord quality played no role in how likely a chord was to be labeled "sad."

This asymmetry in the influence of our manipulated variables was also present in our triads, which were formed by removing the root or the seventh from a major or minor seventh chord. Major triads were more likely to be labeled "happy," which is in line with the general conception of the major modality being associated with positive affect. On the other hand, minor triads were not more likely to be labeled "sad" relative to "bittersweet." Triads made from removing the root of the seventh chord were seen as more "happy" and less "sad," with the reverse being true for triads made from removing the

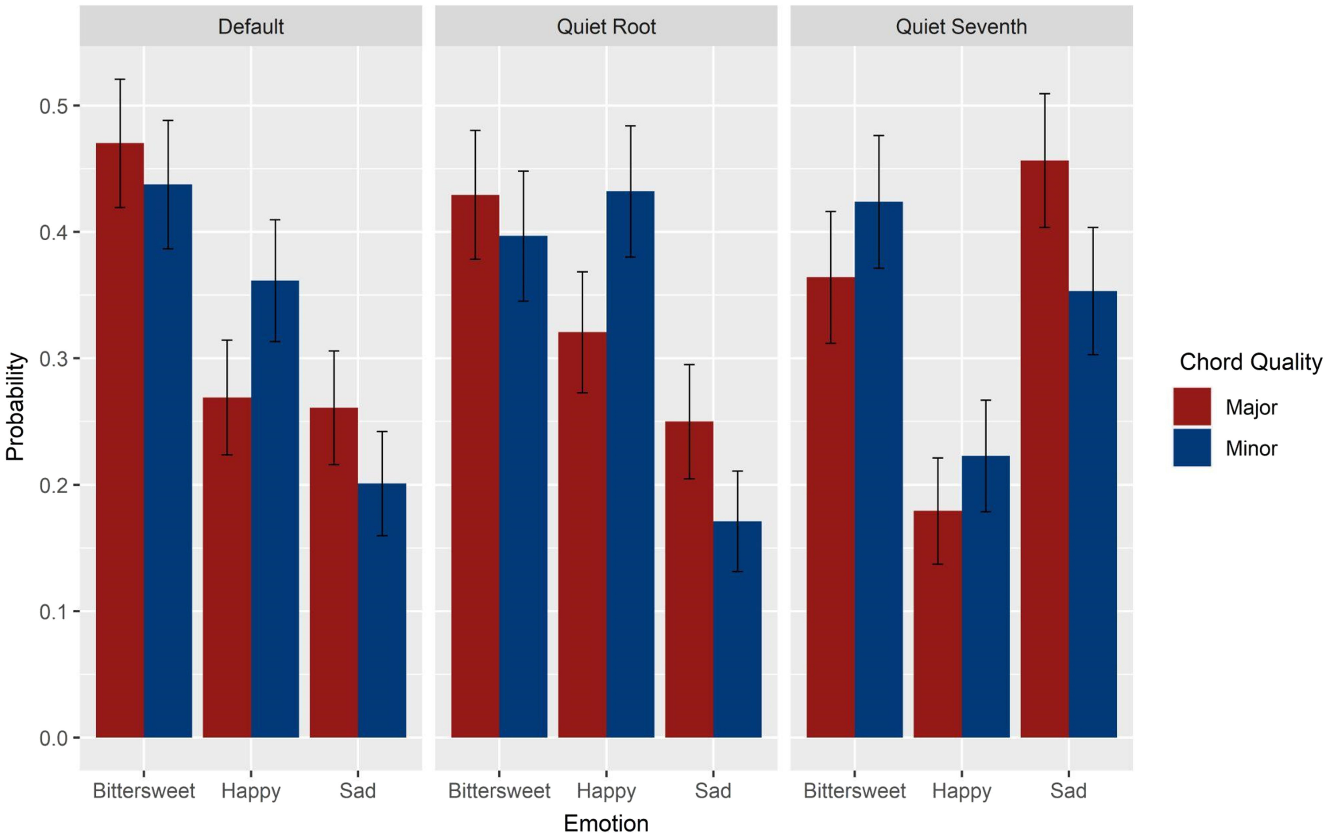
Table 1

Estimates of Effects of Chord Quality and Volume on Ratings of Seventh Chords for Experiment 1

	Happy versus bittersweet			Sad versus bittersweet		
Variable	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	−.424	0.129	.001	−.726	0.130	<.001
Chord quality	−.202	0.090	.025	.100	0.098	.306
Volume (qr/default)	.299	0.126	.017	−.007	0.142	.961
Volume (q7/default)	−.329	0.139	.018	.760	0.131	<.001
Chord Quality × Volume (qr/default)	−.008	0.126	.950	.059	0.142	.678
Chord Quality × Volume (q7/default)	.167	0.138	.226	.121	0.131	.356

Note. qr = quieted chordal root; q7 = quieted chordal seventh.

Figure 2
Probability of Selecting a Given Emotion Label for a Seventh Chord as a Function of Chord Quality (Major/Minor) and Volume (Default Volume, Quieted Root, Quieted Seventh) in Experiment 1



Note. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

seventh. In particular, major triads made from removing the seventh were even more likely to be labeled “sad” relative to “bittersweet.”

The overall influence of the quieting or removal of the seventh on the likelihood of labeling a chord as “sad” suggests there may be an overall pitch height effect present in this experimental design. In other words, the removal of the highest note of a chord results in an overall increase in the perception of negative affect. This effect is particularly strong for influencing perception of negative affect relative to positive affect, whereas perception of positive affect seems to be affected by the modality of the chords as well.

We considered the possibility that the effect of modality, and particularly its interaction with quieting the root/seventh, was not as prominent because the quieted tones were not quieted enough. As such, the subsequent experiment is a response to this hypothesis, in which we manipulated the volume of the root and seventh even further by creating an additional level of volume reduction, thus emphasizing further one of the triads present in a major or minor seventh chord.

Experiment 2

Method

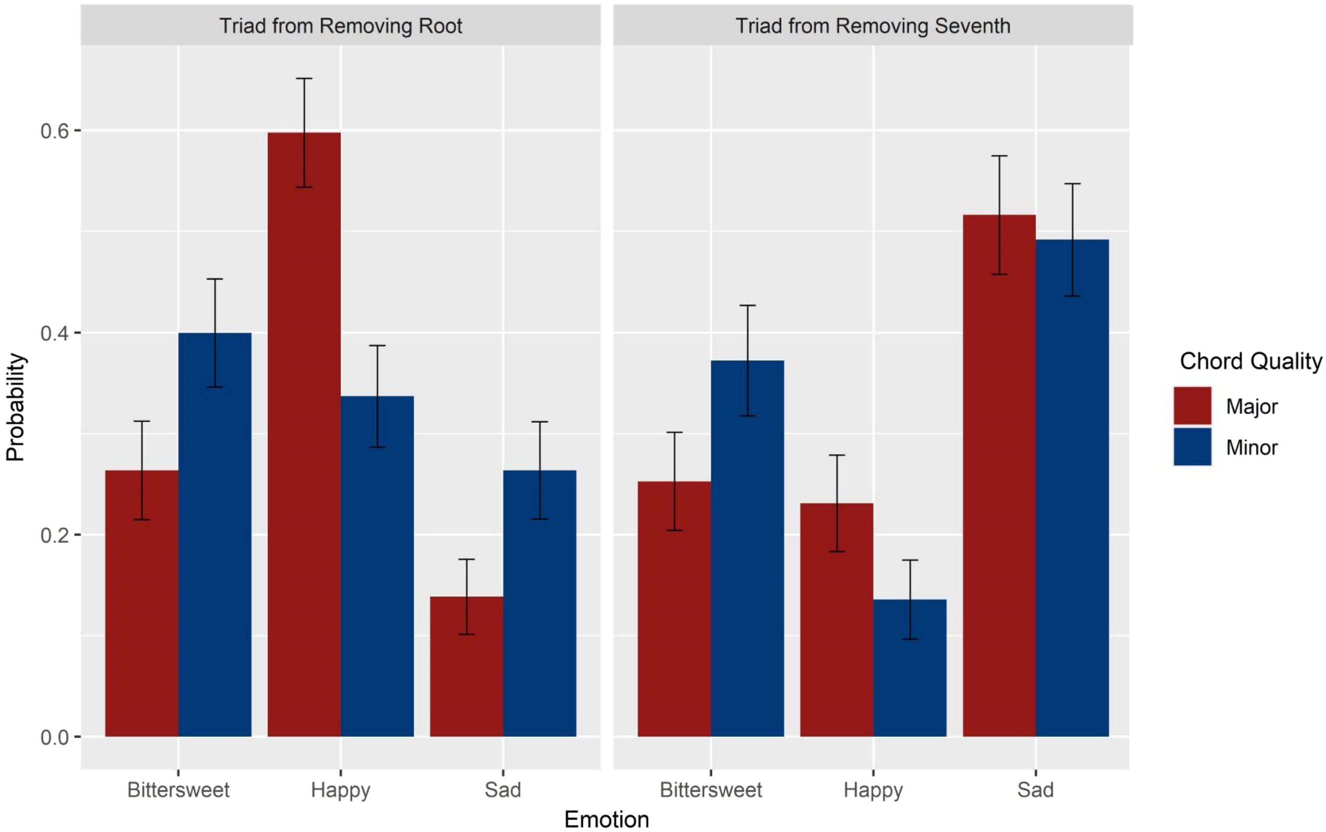
Participants

Eighty-two participants were recruited for Experiment 2. Age was again collected as an ordinal variable, with the following distribution: 18 to 24 years old ($n = 1$), 25 to 34 years old ($n = 17$), 35 to

Table 2
Estimates of Effects of Chord Quality and Volume on Ratings of Triads for Experiment 1

	Happy versus bittersweet			Sad versus bittersweet		
Variable	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	−.135	0.098	.169	−.021	0.092	.817
Chord quality	.496	0.072	<.001	.053	0.070	.448
Chord type	.462	0.072	<.001	−.527	0.070	<.001
Chord Quality × Chord Type	.025	0.072	.731	−.169	0.070	.015

Figure 3
Probability of Selecting a Given Emotion Label for a Triad as a Function of Chord Quality (Major/Minor) and Chord Type



Note. The two chord types are: Triad From Removing the Root on a Major or Minor Seventh Chord and Triad From Removing the Seventh on a Major or Minor Seventh Chord. Note that the removal of the root leaves a triad in the opposite nominal mode of the major or minor seventh chord. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

44 years old ($n = 29$), 45 to 54 years old ($n = 21$), and 55 to 64 years old ($n = 8$), and $n = 6$ not responding. Participants were subject to the same screening criteria as Experiment 1: an age range of 30–60, location in the United States, a minimum prior approval rating of 50%, and no previous participation in other iterations of the study. Like Experiment 1, the sample was also balanced between males and females; survey results reported 36 male and 36 female participants, with one indicating nonbinary and the others choosing not to answer. Participants were not recruited for prior musical training; similarly to Experiment 1, a large majority (77%) did not consider themselves musicians, and more than half reported no experience with an instrument. Sample size was again determined by the availability of funding and the study duration. Because funding was equally distributed between the two experiments, and Experiment 2 had a longer median completion time, less participants could be recruited relative to Experiment 1 in order to maintain compensation at approximately the same fair hourly rate.

In this experiment, one participant completed the experiment but not the subsequent questionnaire. As before, self-reported data from Experiment 2 refers only to the participants ($n = 75$) who completed both portions of the study and were not excluded from analysis. This experiment was authorized by the same protocol as Experiment 1, and all participants received monetary compensation after completing the experiment and questionnaire in their entirety.

Materials

The materials used in Experiment 2 were identical to Experiment 1, with the addition of a new class of stimuli. To explore the response to a new volume interval, we added a "quieter root" and "quieter seventh" designation for each seventh chord. While the "quiet root" and "quiet seventh" had the volume of the specified note reduced relatively to -10 dB, the "quieter root" and "quieter seventh" chords further decreased the volume of the specified note to -15 dB. This resulted in the addition of eight new chords for the participants to judge.

Procedure

The procedure of Experiment 2 was also identical to Experiment 1 with the exception of the addition of the new stimuli. Participants received the same letter of information, gave informed consent, and completed the auditory calibration. After receiving instructions, participants responded to 28 chords—eight new chords and 20 from Experiment 1—before reaching the halfway point attention checks.

Participants then judged all 28 chords a second time before being directed to the follow-up questionnaire. Participants who completed both the experiment and the survey questions in their entirety were given a completion code, which released compensation upon submission to Prolific; with a median completion time of 15 min and 40 s, participants were paid \$3.00 resulting in a mean hourly rate of \$11.49.

Data Exclusion

Exclusionary criteria for Experiment 2 remained the same as for the prior iteration. To that end, five participants were omitted from data analysis for failing to complete all trials of the experiment. Additionally, two participants answered at least one question incorrectly on the halfway point attention check and were thus deemed inattentive to the task. As in Experiment 1, participants were not excluded from analysis based on headphone check performance. After these omissions, 75 participants were considered eligible for primary analysis. Of the participants who met the threshold for inclusion, 66% passed the headphone check.

Data Analysis

The analysis approach was conceptually similar to Experiment 1, although there were some notable differences in the model specifications given the changes in experimental design. With the addition of "quieter root" and "quieter seventh," there were now five levels in the volume variable for major and minor seventh chords. Because Experiment 1 showed asymmetrical responses in the effect of quieting the root and the seventh, and we did not have strictly linear outcomes predicted for comparing the "quiet" and "quieter" versions of volume manipulations, we created two separate variables of quiet root and quiet seventh to quantify the contribution of each of these effects. Quiet root and quiet seventh were ordered factor variables with three levels of q0, q1, and q2, where q0 represents no quieting and q2 represents the "quieter" version. A chord with no volume manipulations was assigned q0 in both variables. Because no seventh chord would have quieting in both the root and seventh at the same time, we modeled the fixed effects of chord quality (contrast-coded as above), quiet root, and quiet seventh, with separate interactions for chord quality and quiet root as well as chord quality and quiet seventh. The model tested linear and quadratic trends for both ordered factors.

Results

Seventh Chords

The results of the multinomial logistic regression are listed in Table 3. Similarly to Experiment 1, the main effect of chord quality was significant only for the happy versus bittersweet contrast. While chord quality affected the likelihood of a chord being labeled as happy, it did not affect the likelihood of it being labeled as sad. The quadratic trend of quiet root was also a significant predictor of a happy rating, where a "quiet root" chord was more likely to be rated happy than "default" or "quieter root." On the other hand, the linear trend of quiet root and quiet seventh were both predictors of a sad rating, such that both quieting the root and quieting the seventh more resulted in an increase in the likelihood of a major or minor seventh chord being rated as sad (although the effect is more prominent by quieting the seventh).

Chord quality also interacted with the linear trend of quiet root, suggesting that the quieter the root got, major seventh chords were less likely to be rated as happy compared to bittersweet while minor seventh chords showed an opposite pattern (more likely to be rated as happy compared to bittersweet). No interactions of chord quality and volume manipulations were seen in comparing likelihoods of sad and bittersweet ratings. The probability of selecting each emotion label for each chord is presented in Figure 4.

Visual inspection revealed a slightly different pattern of responses for default volume major and minor seventh chords in Experiment 2 as compared to Experiment 1. To investigate this difference, as in Experiment 1, we completed an additional analysis with only the default volume chords, while maintaining chord quality as contrast-coded. The results are listed in Table S2 in the online supplemental materials for detailed analysis and are different from the results of Experiment 1, confirming visual observations.

Triads

Model estimates for the effects of chord quality and chord type on the ratings of triads can be seen in Table 4. Overall, we see an effect of both variables on the ratings of how happy triads were perceived

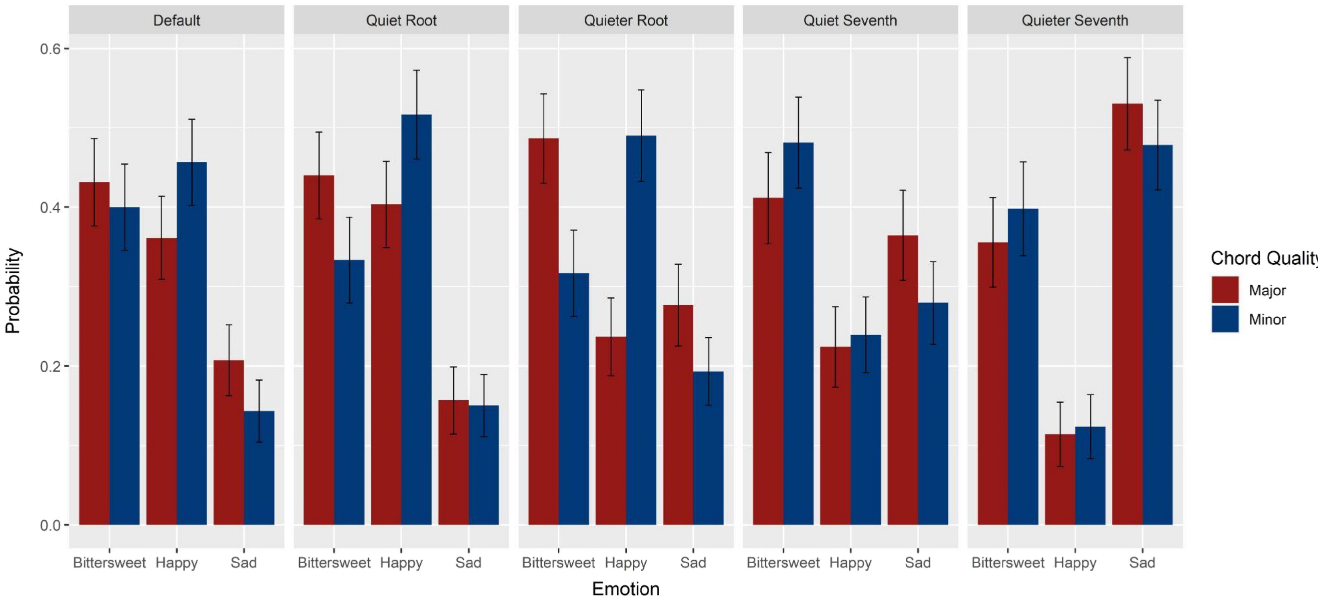
Table 3
Estimates of Effects of Chord Quality and Volume on Ratings of Seventh Chords for Experiment 2

	Happy versus bittersweet			Sad versus bittersweet		
Variable	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	−.634	0.115	<.001	−.220	0.117	.059
Chord quality	−.223	0.080	.005	.011	0.082	.894
Quiet root (L)	−.088	0.097	.364	.265	0.116	.022
Quiet root (Q)	−.228	0.094	.016	.183	0.123	.138
Quiet seventh (L)	−.843	0.118	<.001	.903	0.107	<.001
Quiet seventh (Q)	.062	0.111	.575	.039	0.101	.698
Chord Quality × Quiet Root (L)	−.314	0.097	.001	−.130	0.116	.264
Chord Quality × Quiet Root (Q)	−.092	0.094	.328	.148	0.123	.229
Chord Quality × Quiet Seventh (L)	.132	0.117	.260	−.024	0.107	.822
Chord Quality × Quiet Seventh (Q)	−.096	0.111	.387	−.068	0.101	.501

Note. L = linear trend; Q = quadratic trend.

Figure 4

Probability of Selecting a Given Emotion Label for a Seventh Chord as a Function of Chord Quality (Major/Minor) and Volume (Default Volume, Quiet Root, Quieter Root, Quiet Seventh, Quieter Seventh) in Experiment 2



Note. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

to be. In particular, we see that there is an overall effect of chord type such that a triad that is the result of a quieted root is overall more likely to be rated happy and less likely to be sad relative to bittersweet. However, for a triad that is the result of a quieted seventh, chords are less likely to be rated happy. In addition, there is both a main effect of chord quality and interaction for the happy versus bittersweet comparison, such that major chords are more likely to be rated as happy, especially in triads made by removing the root of a major or minor seventh chord. Such effects of chord quality did not seem to affect how likely an individual was to rate a chord as sad. The probability of selecting each emotion label for each triad is presented in Figure 5. It is important to note that removing the root of a major or minor seventh chord results in a triad with a mode opposite to the nominal mode of the original major or minor seventh chord.

Discussion

In Experiment 2, we sought to both replicate and extend the findings of Experiment 1 by adding volume conditions in which either the root or the seventh were quieted further without being eliminated entirely. We aimed to examine whether it would be possible to tease apart potential interactions between the mode of the seventh chords and the presence of the pitches (root or seventh) which, when attenuated in volume, make the lower or upper triad of the seventh chord more pronounced. Due to the fact that we had no predictions on whether further quieting the root or seventh would result in linear changes, we modeled the effect of quieting the root and seventh separately as both linear and quadratic effects.

We observed an interaction of chord quality and the linear model of quieting the root, in the expected direction: by quieting the root of a major seventh chord, the minor triad was highlighted, making the chord less likely to be rated as "happy" relative to "bittersweet." Conversely, by quieting the root of a minor seventh chord, the major triad was highlighted, and the chord was more likely to be rated as "happy." Although this trend was visually seen in Experiment 1, the condition of quieter root in Experiment 2 highlighted this interaction prominently.

On the other hand, there was no significant interaction of chord quality and quieting the seventh; instead, we observed a similar effect as in Experiment 1, where quieting the seventh resulted in

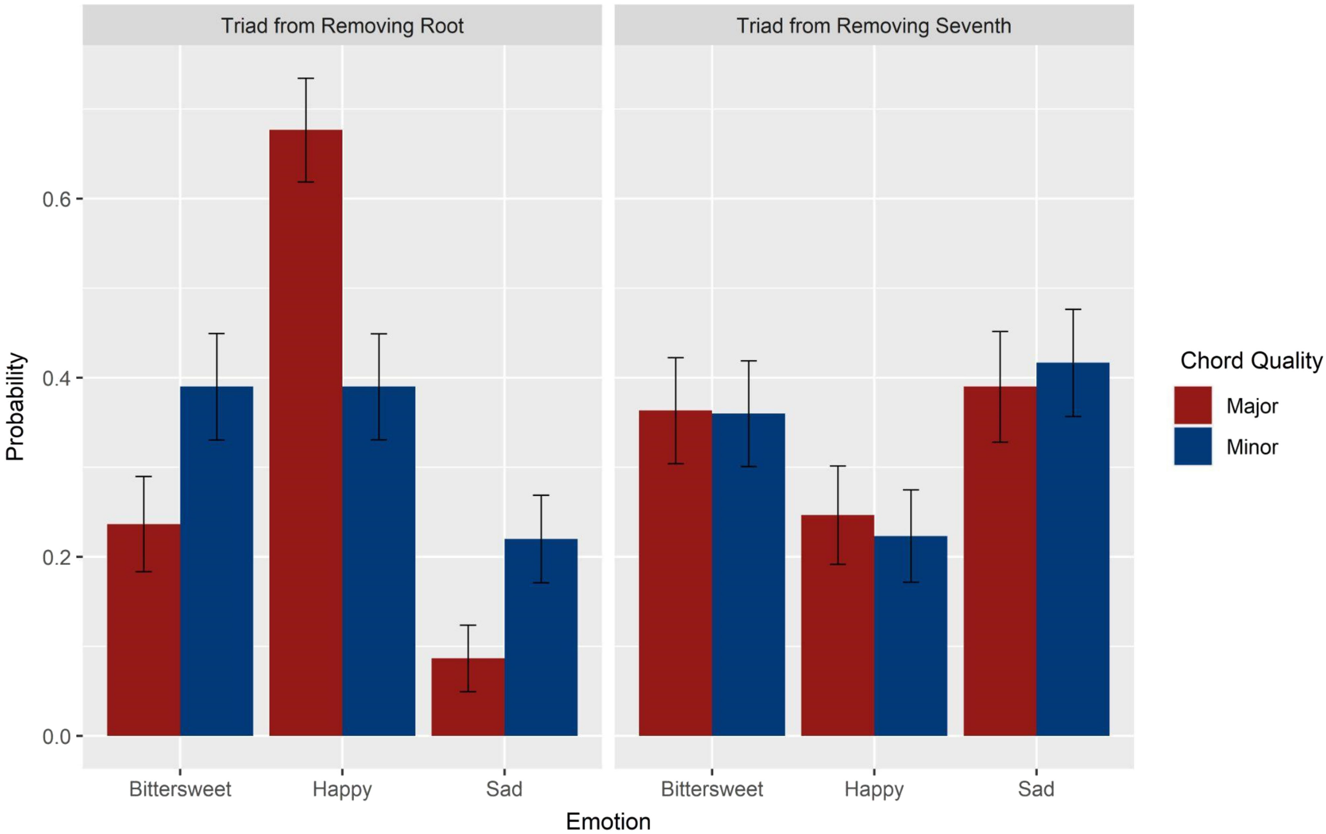
Table 4

Estimates of Effects of Chord Quality and Chord Type on Ratings of Seventh Chords for Experiment 2

	Happy versus bittersweet			Sad versus bittersweet		
Variable	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	.051	0.108	.637	−.351	0.119	.003
Chord quality	.298	0.073	<.001	−.129	0.085	.129
Chord type	.497	0.073	<.001	−.463	0.085	<.001
Chord Quality × Chord Type	.252	0.073	<.001	−.083	0.083	.294

Figure 5

Probability of Selecting a Given Emotion Label for a Triad as a Function of Chord Quality (Major/Minor) and Chord Type



Note. The two chord types are: Triad From Removing the Root on a Seventh Chord, Triad From Removing the Seventh on a Seventh Chord. Note that the removal of the root leaves a triad in the opposite nominal mode of the major or minor seventh chord. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

an increase in likelihood of rating the chord as "sad." Interestingly, quieting the root of a major or minor seventh chord also increased its likelihood of being rated as "sad," although that effect was not as strong as quieting the seventh. As in Experiment 1, this effect of quieting the seventh did not interact with chord quality, suggesting that ratings of "sad" were not dependent on the tonality of the chord the same way that ratings of "happy" were. Surprisingly, the perceived emotion ratings for unmanipulated major and minor seventh chords were different from Experiment 1, as these chords were equally likely to be rated as happy and as bittersweet. However, there was still a significant difference in perception between major and minor seventh chords, in that the latter were more likely to be rated as happy than the former.

Regarding the triads, although there was no difference in the stimulus or task between Experiments 1 and 2, the analyses revealed slight differences. There was a replication of the main effects of chord quality and chord type, but the interaction of these two variables affected the likelihood of a chord being labeled sad in Experiment 1 while affecting happy in Experiment 2. Visual inspection suggests that the difference in response pattern for triads made by removing the seventh underlies the variation in the interaction term, where the response pattern for triads made by removing the root are similar.

Although there was a general agreement between the findings of Experiments 1 and 2, there are some notable limitations with respect to the experimental design that might constrain the generalizability of our findings. Our decision in Experiments 1 and 2 to adopt a forced-choice paradigm with choices of "happy," "sad," and "bittersweet" was motivated by a desire to simplify the participant experience, as well as to observe whether the models used in analysis would converge meaningfully despite a more basic paradigm. One major drawback of this decision is that our participants were limited in their ability to express more nuanced judgments for analysis (e.g., being able to express that a chord was some combination of more than one emotion category). Additionally, only including one mixed-emotion response option deviates from prior studies, notably Lahdelma and Eerola (2016a, 2016b). Only including a single mixed-emotion category also opens up the possibility that participants could have used the "bittersweet" option to express uncertainty about choosing between the two absolutes of "happy" or "sad" (i.e., selecting the ambivalent emotion choice as a proxy for "I don't know"). Experiment 3 was thus designed to conceptually replicate the findings of Experiments 1 and 2 while modifying the experimental design to directly address these concerns.

Experiment 3

Method

Participants

Four hundred participants were recruited for Experiment 3, and we received 390 responses. Age was again collected as an ordinal variable, with the following distribution: 18 to 24 years old ($n = 31$), 25 to 34 years old ($n = 101$), 35 to 44 years old ($n = 115$), 45 to 54 years old ($n = 73$), 55 to 64 years old ($n = 41$), and over 65 years old ($n = 29$). The sample was again largely balanced between men and women; survey results reported 186 male and 194 female participants, with eight indicating nonbinary and one electing not to answer. While participants were selected using nearly all the same filters as the first two experiments, we elected to remove the age range requirement of 30 to 60 years old. After further consideration, the requirement that all participants have no hearing impairment eliminated the major concern that would be most likely to affect elderly participants. Furthermore, while it remains probable that adults of at least 30 years of age have had greater lived experience than adults just turning 18, prior research suggests that children as young as seven are capable of experiencing simultaneous emotions, namely happiness and sadness (Burkitt et al., 2018). Therefore, we posit that younger adults would show a negligible difference in comprehension of bittersweetness relative to their slightly older counterparts. Sample size was largely based on similar studies examining perception of single vertical chords reported by Lahdelma and Eerola (2016a, 2016b), who analyzed 269 and 410 participants, respectively.

We also continued the trend of selecting participants without regard for prior musical training; similar to Experiments 1 and 2. In Experiment 3, we asked participants about their musical status through both self-report measures and a brief music theory assessment (see Procedure for details). Before applying exclusionary criteria, most participants (85%) self-reported that they did not consider themselves musicians, and nearly two-thirds (63%) reported no experience with an instrument. Additionally, performance on the music theory assessment was quite poor (see Results section). Taken together, these results suggest that the sample was largely musically untrained.

In this experiment, five participants completed the experiment but not the subsequent questionnaire. As before, self-reported data from Experiment 3 refers only to the participants ($n = 358$) that completed both portions of the study and were not excluded from analysis. This experiment was authorized by the same protocol as the prior pair, and all participants again received monetary compensation after completing the experiment and questionnaire in their entirety.

Materials

Experiment 3 tested 42 total chords. Each tested major and minor seventh chord had five versions: (a) a default (no quieting of either the root or seventh), (b) a quiet root (−10 dB), (c) a quiet seventh (−10 dB), (d) a quieter root (−15 dB), and (e) a quieter seventh (−15 dB). To better disentangle the effects of pitch height, we presented three versions of the major and minor seventh chords differing in terms of the pitch class of the root note (Ab, C, and Eb), meaning there were 30 tested seventh chords (Five Versions [Default, Quiet Root, Quiet Seventh, Quieter Root, Quieter Seventh] × Three Pitch Classes [Ab, C, Eb] × Two Seventh Chords [Major, Minor]). We additionally tested six major and six minor triads, which were derived from the tested major and minor seventh chords with either the root or the seventh completely quieted. Participants completed the chord ratings and music theory assessments in jsPscyh (de Leeuw, 2015) and completed the final questionnaire in Qualtrics.

Procedure

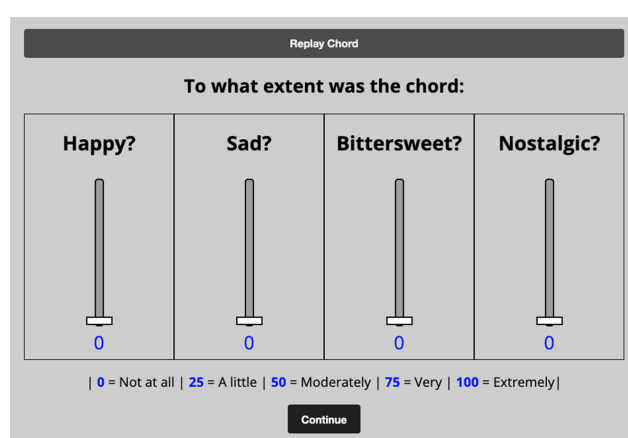
The procedure of Experiment 3 differed significantly from Experiments 1 and 2. One of the pitfalls of using a forced-choice paradigm, as was done in Experiments 1 and 2, is that the data cannot capture the strongest degree of nuance from a participant's emotional evaluations. For example, if a participant felt that a chord seemed equally sad and bittersweet, but not happy, the prior paradigm would not allow a response that reflects such a judgment. As such, in this experiment, a set of sliders were introduced that allowed each emotion to be rated relative to the others on the same screen (see Figure 6).

As shown in the figure, after hearing a chord, participants were shown four sliders, one per emotion, which were always set at a baseline value of "0." The key offered descriptors of "not at all," "a little," "moderately," "very," and "extremely" for each quartile to help participants calibrate their responses. In addition, to better emulate the study done by Lahdelma and Eerola (2016a), we introduced the emotional adjective "nostalgic" as a second mixed-emotion category. Finally, a "replay chord" button was added above the sliders to ensure the participants were as familiar with the stimulus as they felt they needed to be when making their emotional judgments.

Another notable difference between Experiment 3 and the previous experiments was the inclusion of a music theory assessment. This assessment consisted of two self-report questions ("Do you know how to read musical notation?" [yes/no] and "How would you rate your understanding of music theory?" [very poor/poor/fair/good/very good]). In addition to these self-report questions, participants completed a performance-based assessment of music theory, which consisted of a visual matching task (eight trials) and an

Figure 6

Answer Input Screen From the Modified Response Paradigm Used in Experiment 3



Note. See the online article for the color version of this figure.

auditory matching task (eight trials). In the visual matching task, participants were shown the name of a chord (augmented triad, diminished triad, major triad, minor triad) and were given four response images of musical notation, with one being the correct answer. In the auditory matching task, participants were presented with an auditory version of the triad (e.g., an augmented triad) and were similarly given four response images of musical notation, with one being the correct answer. As such, chance performance in both assessments was 25% (two of eight trials).

Outside of these specific changes to data collection and the participant experience, the format of Experiment 3 remained largely the same. Participants again received the same letter of information, gave informed consent, and completed the auditory calibration and headphone check. After receiving instructions and completing an attention check, participants responded to the 42 chords in a randomized order. Immediately following the chord judgments, participants completed a second attention check and then completed the music theory assessment. Following the music theory assessment, participants were redirected to the follow-up questionnaire. Participants who completed both the experiment and the survey questions in their entirety were given a completion code and subsequently paid for their time; the experiment had a median completion time of 24 min, and participants received \$3.36 for a mean hourly rate of \$8.40.

Data Exclusion

Exclusionary criteria for Experiment 3 remained the same as for Experiments 1 and 2. To that end, 31 participants were omitted from data analysis for answering at least one question incorrectly on the halfway point attention check and were thus deemed inattentive to the task. As in Experiments 1 and 2, participants were not excluded from analysis based on headphone check performance. After these omissions, 358 participants were considered eligible for primary analysis. Of the participants who met the threshold for inclusion, 63.6% passed the headphone check.

Data Analysis

With the introduction of continuous slider data as a measure rather than an alternative forced choice, we changed to using linear mixed models. Since initial analyses of the correlation between data sets revealed that there was some collinearity in our dependent variables (the four emotions on which each chord sequence was rated), we analyzed the data using multivariate linear mixed models via lme4 in R, Version 4.2.1 (R Core Team, 2022). The model included a random intercept for each participant, separated for each of the four dependent variables. To ensure that there is a separate effect for our dependent variables of interest in a linear mixed model, which term was measured as a dependent variable (term) was also entered as a fixed effect that interacted with our independent variables of interest, chord quality (contrast-coded as above), quiet root, and quiet seventh, with separate interactions for chord quality and quiet root as well as chord quality and quiet seventh. Fixed effects of this multivariate model were assessed using Wald chi-square tests on deviance tables (function "Anova" on package "car").

Data were subsequently analyzed using four linear mixed models, one for each dependent variable. The model included a random intercept for each participant. Similar to Experiment 2, we modeled the fixed effects of chord quality (contrast-coded as above), quiet root, and quiet seventh, with separate interactions for chord quality and quiet root as well as chord quality and quiet seventh. The model tested linear and quadratic trends for both ordered factors. Fixed effects were subsequently assessed by using Wald chi-square tests on deviance tables to determine overall statistical significance. To account for multiple comparisons, p-values for the fixed effects and interactions across the four dependent variables were extracted and corrected using the false discovery rate (function "p.adjust" with method "fdr"). To examine significant fixed effects, estimated marginal means were computed and differences between volume conditions compared using package "emmeans" (Lenth, 2022). Performance on the music theory assessment was analyzed using a one-sample t-test against chance performance (two of eight trials correct for both the visual matching and auditory matching tasks). We additionally calculated two one-sided tests used the TOSTER package (Lakens, 2017) to assess whether mean performance on the music theory assessment was equivalent to a range of scores between 1 and 3 out of 8, as this represents the smallest practical difference of interest (given that the smallest above-chance score that could be achieved by a participant would be 3 out of 8).

Results

Seventh Chords

For the multivariate linear mixed model, there were significant effects of term, $\chi^2(4) = 3{,}544.40$, $p < .001$, term and quiet root, $\chi^2(4) = 58.19$, $p < .001$, term and quiet seventh, $\chi^2(4) = 43.22$, $p < .001$, as well three-way interactions of term, quiet root, and chord quality, $\chi^2(4) = 24.34$, $p < .001$, and term, quiet seventh, and chord quality, $\chi^2(4) = 48.41$, $p < .001$, were all significant, justifying a univariate model for each dependent variable tested below.

Table 5

Wald χ^2 Tests Assessing Statistical Significance of the Fixed Effects of Chord Quality and Volume on Ratings of Seventh Chords for Experiment 3

Dependent measure	Predictor	χ^2	p
Happy	Chord quality	0.059	.851
	Quiet root	21.90	<.001
	Quiet seventh	5.79	.074
	Chord Quality × Quiet Root	9.99	.015
	Chord Quality × Quiet Seventh	9.12	.021
Sad	Chord quality	7.81	.015
	Quiet root	8.60	.025
	Quiet seventh	12.10	.009
	Chord Quality × Quiet Root	4.57	.127
	Chord Quality × Quiet Seventh	28.11	<.001
Bittersweet	Chord quality	0.45	.590
	Quiet root	16.78	.001
	Quiet seventh	6.17	.065
	Chord Quality × Quiet Root	7.79	.034
	Chord Quality × Quiet Seventh	6.20	.065
Nostalgic	Chord quality	8.63	.011
	Quiet root	10.19	.015
	Quiet seventh	20.92	<.001
	Chord Quality × Quiet Root	0.89	.714
	Chord Quality × Quiet Seventh	0.10	.952

Note. p-values are corrected for multiple comparisons by controlling the false discovery rate.

The results of the Wald chi-square tests on the fixed effects of the four linear mixed models can be seen in Table 5. As predicted, and to more visible effect in this experiment, chord quality interacted with quieting the root or seventh in almost opposite patterns for perceiving "happy" or "sad" in a given major or minor seventh chord. While quieting the root increased ratings of happiness, this effect was not found for major seventh chords where quieting the root highlights the upper minor triad (all comparisons n.s.) and instead specific to minor seventh chords where quieting the root highlights the upper major triad (default vs. quiet, $p < .001$; default vs. quieter, $p < .001$; quiet vs. quieter, $p = .743$). Quieting the seventh had the opposite effect on ratings of happiness, to a lesser extent. This effect was almost entirely reversed for ratings of sadness; while quieting the root decreased ratings of sadness (default vs. quiet, $p = .025$; default vs. quieter, $p = .036$; quiet vs. quieter, $p = .992$), this did not significantly differ between major and minor sevenths. However, while quieting the seventh on a major seventh did not significantly change sadness ratings (all comparisons n.s.), but quieting the seventh on a minor seventh increased ratings of sadness (default vs. quiet, $p = .003$; default vs. quieter, $p < .001$; quiet vs. quieter, $p = .011$).

For our emotion of interest, ratings of bittersweetness did not significantly vary between major and minor sevenths. Quieting the root or the seventh of the chord decreased ratings of bittersweetness, although the effect of quieting the seventh was not statistically significant. Furthermore, the effect of quieting the root was observed primarily for minor sevenths (default vs. quiet, $p = .076$; default vs. quieter, $p < .001$; quiet vs. quieter, $p = .024$), and not for major sevenths (all comparisons n.s.). Interestingly, the second mixed emotion term "nostalgic" was endorsed slightly differently in comparison to endorsements for "bittersweet," with an interaction effect of quieting the root on the effect of chord quality in "bittersweet" that was not seen for "nostalgic" and a slight increase in "nostalgic" ratings across all major sevenths not seen for "bittersweet." That said, quieting the root (default vs. quiet, $p = .952$, default vs. quieter, $p = .010$; quiet vs. quieter, $p = .025$) or the seventh (default vs. quiet, $p = .001$, default vs. quieter, $p < .001$; quiet vs. quieter, $p = .720$) both decreased ratings of "nostalgic." The mean ratings for each chord are presented in Figure 7.

Since the results of Experiments 1 and 2 suggested a prominent role of pitch height in determining whether or not a chord was deemed more happy or sad, we repeated the analysis, now adding as a covariate the root of the chord as an ordered factor proxy for pitch height. While pitch height on its own became a significant factor, nothing was changed with regard to the effects of chord quality or volume. Full results of this analysis can be found in Table S3 in the online supplemental materials.

Triads

The results of the Wald chi-square tests on the fixed effects of the four linear mixed models can be seen in Table 6. The main effect of chord quality was seen in the ratings of all emotions except for "nostalgic"; however, there was no effect of chord type as there was in Experiments 1 and 2. Minor triads were rated as more "bittersweet" and more "sad" than major triads, but major triads were rated as more "happy" than minor triads (Figure 8).

Music Theory Assessment

Mean performance for the visual matching task was 2.07 ($SD =$ 1.62), which was not significantly above chance, $t(357) = 0.84$, $p = .399$, $d = 0.04$, and was equivalent to the smallest range of interest—that is, performance between 1 and 3 out of 8, $t(357) = -10.79$, $p < .001$. Mean performance for the auditory matching task was 2.46 ($SD = 1.49$), which was significantly above chance, albeit with a small-to-medium effect size, $t(357) = 5.87$, $p < .001$, $d = 0.31$. Auditory matching task performance was also equivalent to the smallest range of interest—that is, performance between 1 and 3 out of 8, $t(357) = -6.80$, $p < .001$. For the self-report questions, only 17.9% of participants reported that they knew how to read music notation, and participants' self-reported understanding of music theory was 1.80 ($SD = 0.86$), on a 5-point scale, with a modal response of 1.

Discussion

In Experiment 3, we asked participants to evaluate the degree to which a chord represented each of four emotions, rather than asking participants to choose one emotion it best portrayed. Using a different paradigm, and including a second mixed emotion term "nostalgic," we largely replicated the pattern of findings observed in Experiments 1 and 2. Importantly, the addition of chords in different musical keys addressed the asymmetrical effects we saw of pitch height and mode, since quieting the root or the seventh no longer necessarily meant the increase or decrease of the same pitch height. Thus, in Experiment 3, we observed our initial prediction that quieting the root or the seventh in a major or minor seventh chord would have different effects on ratings of happiness or sadness depending on the mode of the seventh chord.

When it came to how well a major or minor seventh chord represented "bittersweet," we initially predicted that a major or minor seventh chord could represent "bittersweet" well, as seen in Experiments 1 and 2 where it was endorsed more as "bittersweet" when the chord was intact. This was indirectly supported by the fact that both quieting the root or the seventh—in other words, disrupting the integrity of the chord—reduced the perception of "bittersweet" in the chord. In further support of the major and minor seventh chord as representing mixed emotion, this pattern was also seen for "nostalgic."

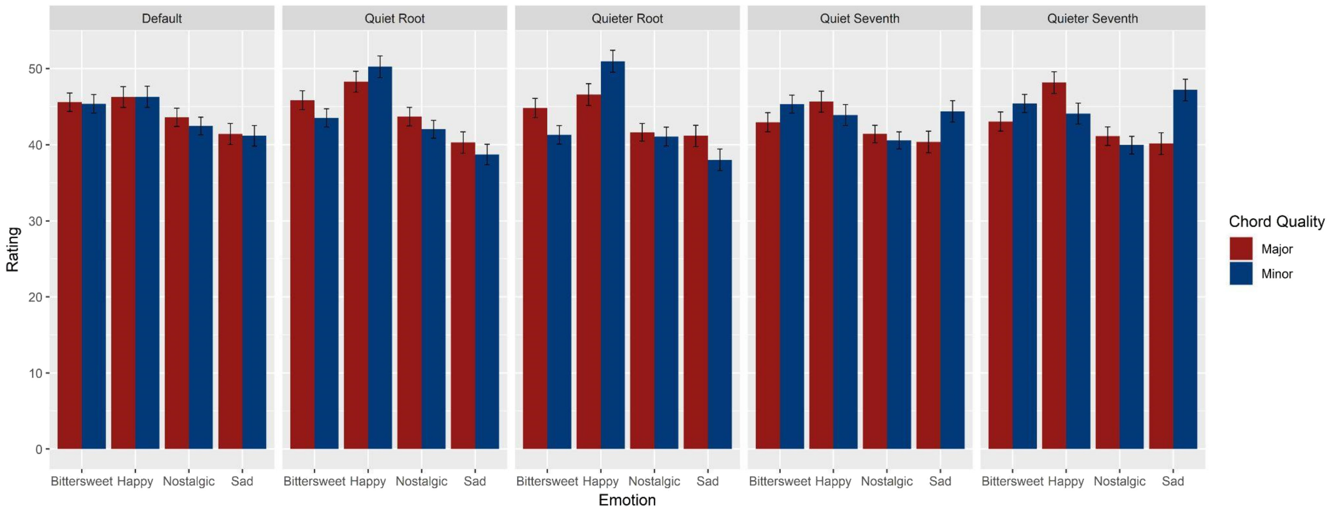
Regarding triads, while the effect of chord quality persisted, the effect of chord type did not. This is presumably due to the fact that in Experiment 3, we introduced chords in multiple keys that spanned a range of pitch height, such that removing the root or the seventh was no longer necessarily linked to pitch height. As such, the typical association of major triads being perceived as more "happy" and minor triads more "sad" was observed. Whereas ratings of "nostalgic" were not affected by any manipulated variable, ratings of "bittersweet" followed the same pattern as that of "sad."

General Discussion

This study sought to investigate the effect of mode on the perceived emotions in major and minor seventh chords. Given that the major and minor modes in triads have conventionally been associated with happiness and sadness respectively in Western music, and that major and minor seventh chords have been theoretically (Cooke, 1959; Everett, 2008) and empirically (Lahdelma & Eerola, 2016a) associated with the mixed "bittersweet" emotion of nostalgia, we hypothesized that the affect associated with different modes could be brought out by articulating the triadic components

Figure 7

Rating for Perceiving a Given Emotion Label for a Seventh Chord as a Function of Chord Quality (Major/Minor) and Volume (Default Volume, Quiet Root, Quieter Root, Quiet Seventh, Quieter Seventh) in Experiment 3



Note. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

in major and minor seventh chords. It was expected that making these triadic components more audible by lowering the volume of the root or the seventh would result in boosting perceived emotion ratings of the emerging triad, making the seventh chords less likely to be perceived as bittersweet.

Our results suggest that the effects of mode on emotion perception are more complex than anticipated. Some findings aligned with expectations: for example, the data from the unmanipulated major and minor seventh chords in Experiment 1 confirmed that these chords were more likely to be perceived as expressing a mixed emotion (i.e., bittersweetness) than a single-valence emotion (happiness or sadness). However, the bittersweet ratings were not at ceiling and both major and minor seventh chords were also perceived as both sad and happy individually, which replicated the findings of Lahdelma and Eerola (2016a); they found that emotion ratings of these chords were higher for nostalgia, but did not have starkly different happiness and melancholy ratings.

Table 6

Wald χ^2 Tests Assessing Statistical Significance of the Fixed Effects of Chord Quality and Volume on Ratings of Triads for Experiment 3

Dependent measure	Predictor	χ^2	p
Happy	Chord quality	172.21	<.001
	Chord type	2.62	.211
	Chord Quality × Chord Type	1.58	.359
Sad	Chord quality	141.51	<.001
	Chord type	3.46	.151
	Chord Quality × Chord Type	4.13	.127
Bittersweet	Chord quality	53.80	<.001
	Chord type	0.34	.672
	Chord Quality × Chord Type	0.01	.921
Nostalgic	Chord quality	0.86	.531
	Chord type	0.16	.749
	Chord Quality × Chord Type	0.46	.665

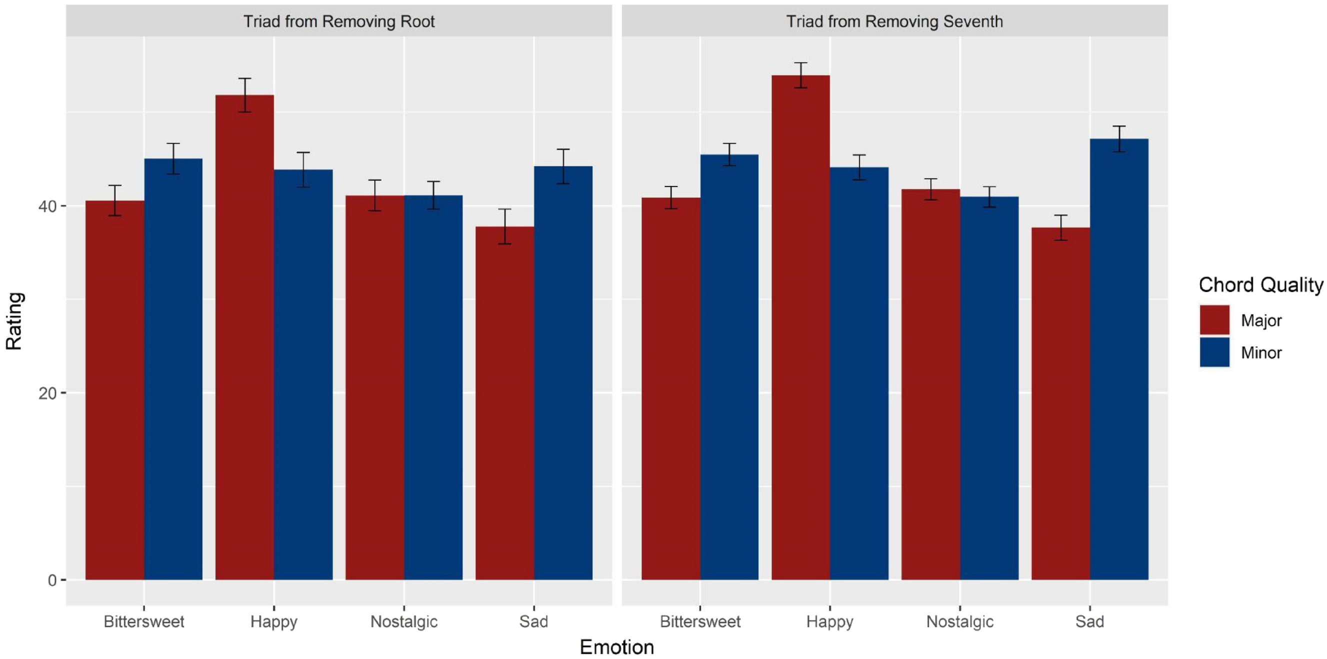
Note. p-values are corrected for multiple comparisons by controlling the false discovery rate.

Furthermore, a modal effect was observed with respect to happiness ratings across all experiments; major triads resulting from a rootless seventh were rated as happier, but the minor triads were not. However, in Experiments 1 and 2, a very unexpected finding emerged; mode had no effect on the likelihood of any type of chord being rated as sad relative to the bittersweet condition.

We further observed surprising asymmetries in emotion ratings for both major and minor seventh chords and triads. First, while data from Experiment 1 revealed a higher likelihood of a seventh chord being labeled as bittersweet than either happy or sad, in Experiment 2, the same chords were just as likely to be labeled as bittersweet as they were happy. This trend of bittersweet ratings tracking with happy ratings was also nominally observed (for unaltered major and minor seventh chords) in Experiment 3, although the statistical approach taken in Experiment 3 did not directly test for this. Future work might consider examining the factors (e.g., contextual factors of the listening experiment, individual factors of the participants) that might contribute to major and minor seventh chords being heard as more distinctly bittersweet (as was observed in Experiment 1). Second, in both Experiment 1 and Experiment 2, the happy and sad ratings of the unmanipulated major and minor seventh chords were opposite to what one would expect from their nominal mode: major seventh chords were rated as both sadder and less happy than minor seventh chords, and minor seventh chords were rated happier and less sad than major seventh chords—a finding that potentially supports the acoustic roughness explanation of mixed emotion in major and minor seventh chords (e.g., Lahdelma & Eerola, 2015). Third, prior literature would suggest that triads in both experiments would have shown an unambiguous effect of mode (Bakker & Martin, 2015; Crowder, 1984, 1985; Gagnon & Peretz, 2003; Gerardi & Gerken, 1995); in the present study, the expected biases toward happiness and sadness as a whole are not observed in Experiments 1 and 2, where pitch height was a salient cue. In contrast, Experiment 3, which introduced multiple versions of the chords across a wider range of pitch registers,

Figure 8

Rating for Perceiving a Given Emotion Label for a Triad as a Function of Chord Quality (Major/Minor) and Chord Type in Experiment 3



Note. The two chord types are: Triad From Removing the Root on a Seventh Chord, Triad From Removing the Seventh on a Seventh Chord. Note that the removal of the root leaves a triad in the opposite nominal mode of the major or minor seventh chord. Error bars represent the 95% confidence interval. See the online article for the color version of this figure.

showed the expected biases toward happiness and sadness. These results suggest that mode may not be as salient in emotional associations as previously understood. It is clear that other aspects besides changes in mode (most notably in the present study, pitch height, as well as making judgments in a larger context of major and minor seventh chords) also contribute meaningfully to participants' emotional interpretations of the stimuli.

When examining factors that may have influenced emotion ratings for chords, several interactions were observed involving pitch height. First, as mode had no effect on sadness ratings, pitch height was the only variable that had a significant effect on the likelihood of rating a chord as more or less sad relative to bittersweet. This is seen across Experiments 1 and 2: quieting or removing a chordal seventh from either type of seventh chord, which makes the highest note in the resulting triad lower, increases the likelihood of a sad rating. However, quieting or removing the root of the chord, which makes the lowest note of the triad higher, does not result in a corresponding decrease in the likelihood of a sad rating. Second, the data reflect that major triads are perceived as happier when built as the upper triad of a rootless seventh chord, meaning that the triad's lowest note sits at a greater pitch height. On the other hand, when a major triad is part of a seventhless seventh chord, meaning it sits on a lower note, it is not perceived as happy to the same degree. Third, there was a small effect in Experiments 1 and 2 in which minor sevenths were rated as happier than major sevenths at default volume. In Experiment 2 specifically, further volume manipulations of the lowest note in these chords make this effect more pronounced, again suggesting that pitch height is at play. These findings reflect a strong association between height and perceived mood, namely that higher pitched chords are thought to be happier and less sad, and lower pitched chords are more likely to be perceived as sadder and less happy when compared to bittersweet, respectively.

Importantly, in Experiment 3, the addition of a greater variety of chords across registers eliminated these effects, presumably because the variability in pitch height across chords made pitch height a less salient cue to use in emotion judgments. A robust body of literature affirms that pitch height is a salient auditory cue that listeners are drawn to when making judgments in fields including music, language, and spatial perception (Bongiovanni et al., 2023; Huron et al., 2006; Krishnan et al., 2017; Rusconi et al., 2006). Taking all of these considerations together, the results of these experiments suggest that, given a particular listening context, people are sensitive to pitch height in ways that have a more pronounced effect on emotion perception than modal manipulations do. That being said, we acknowledge that most of the participants in the present study were musically untrained, and so an interesting avenue for future work would be to see how musical expertise influences the weighting of cues (e.g., modal vs. pitch height) in these kinds of judgments (cf., Bidelman et al., 2011; Lahdelma & Eerola, 2016a).

The findings of the present study call into question how the modalities of major and minor are actually being processed by the average listener, particularly in response to more complex stimuli like seventh chords. It is entirely possible that, while music theorists suggest an interpretation of seventh chords as interlocking major and minor triads (see Figure 1), the musical novice does not attend to two distinct modalities within the chord. Instead, most listeners might base affective judgments of major and minor seventh chords on something different altogether, potentially relying on learned experiences with these chords, such as in film music (e.g., Lahdelma & Eerola, 2015), or even interpreting affect based on the psychoacoustic (rather than music theory) properties of the chords (cf., Harrison & Pearce, 2020). Indeed, a robust body of literature indicates that emotion perception in general is subject to a high degree of individual variability (e.g., Kim et al., 2022; McIver et al., 2018). Prior experimentation may provide a framework for understanding these results. In a 2013 study, Chubb et al. (2013) created a sound texture called a "tone scramble" for the purposes of testing whether people can adequately distinguish between major and minor modes in quasimusical contexts. They found a pronounced bimodal distribution; while a smaller percentage of participants were able to distinguish between modes at near-perfect rates, the majority of listeners performed at chance. As an exploratory follow-up, Chubb adjusted the paradigm to observe whether asking participants to respond with the common emotional association—"happy" or "sad" instead of "major" or "minor"—in response to the scrambles would result in improved performance. The data reflected no change in accuracy among the at-chance performance group. The authors concede that there is a "modest" correlation between performance and musical training but purport that it cannot sufficiently explain the entirety of the findings. The study, as well as Chubb's subsequent work (e.g., Ho et al., 2022; Mednicoff et al., 2018), argue that different forms of expertise may inform differing frameworks of emotional perception. Taking these conclusions into consideration, it is possible that those who cannot easily distinguish between major and minor modalities, whether due to lack of musical training or otherwise, are more inclined to attend to pitch height in making their emotional associations. Conversely, those who are able to differentiate the modes or who have substantial musical training may default to, or at least may be aided by, the cultural modal understanding supported by some of the literature.

One potential limitation of the present experimental design is its online delivery format. Because study participants are not physically present in a controlled environment during experimentation, it is more difficult to ensure participants are engaging with the expected tasks with their full attention and effort. However, we are confident that the experimental design has mitigated any risk of poor data quality. Specifically, the experiment code and the functionality of the Pavlovia server were rigorously beta-tested on a variety of different computers to ensure successful delivery. Furthermore, our employment of performance filters ensured that only the best Prolific users with a proven record of quality participation could be a part of the study, Finally, attention checks ensured that participants who turned off their sound, for example, or were otherwise inattentive to the task would not affect the final analysis. Given that recent literature has suggested that properly controlled online psychophysics experiments can yield comparable results to in-lab studies (Eerola et al., 2021; Zhao et al., 2022), we expect these results to replicate in a lab setting, although this should be verified by future work.

Another potential limitation of the present study was the specific focus on major and minor seventh chords. Although major and minor seventh chords were chosen because of their theoretic and empirical associations with mixed emotional states, we acknowledge that this represents a small fraction of potential chords used in Western music, even among seventh chords. Future work may thus consider expanding upon these results to include a greater variety of seventh chords commonly used in Western music contexts (e.g., dominant seventh chords, diminished seventh chords, augmented seventh chords).

As a possibility for future experimentation, further work could involve using neuroimaging to observe the brain's physical response to various chords with different modes. Considering that the brain responds in different ways to manifest feelings of happiness and sadness (e.g., Habel et al., 2005), it is possible that playing a bittersweet chord would allow us to observe which emotional signatures in the brain are active and to what degree relative to each other. Such a design could serve as another way of considering the complexity of mixed emotional categories directly, without the need to rely on self-reporting of the participants' perceived emotions.

Conclusion

Though the ability of music, as well as specific musical features, have long been recognized for their ability to evoke emotion, the effects of mode on complex vertical harmony are less studied. The present set of experiments considered how simple and mixed emotions might manifest in seventh chords containing triads from two modalities, particularly when changing the relative saliency of each mode through targeted volume adjustments to key notes. Results revealed strikingly asymmetrical findings: whereas mode affected the likelihood of a seventh chord being rated as happy or bittersweet, pitch height was the only variable to affect sadness ratings when it was a salient cue (Experiments 1 and 2). These findings suggest that bittersweetness is a complex emotion which cannot be neatly explained as an equal combination of happiness and sadness and may be subject to a significant degree of individual variability. Furthermore, the data demonstrate that pitch height proves a strong surface-level auditory cue to which listeners are drawn in making perceptual judgments. Taken together, the present study calls into question the degree to which commonly held mode–emotion associations are ubiquitous in Western tonal music. Understanding the nuances of how seventh chords are perceived by the listener, as evidenced by these surprising outcomes, warrants further exploration.

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