Perception and Familiarity of Diatonic Modes

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In a prior study (Temperley & Tan, 2013), participants rated the "happiness" of melodies in different diatonic modes. A strong pattern was found, with happiness decreasing as scale steps were lowered. We wondered: Does this pattern reflect the familiarity of diatonic modes? The current study examines familiarity directly. In the experiments reported here, college students without formal music training heard a series of melodies, each with a three-measure beginning ("context") in a diatonic mode and a one-measure ending that was either in the context mode or in a mode that differed from the context by one scale degree. Melodies were constructed using four pairs of modes with the same tonic: Lydian/Ionian, Ionian/Mixolydian, Dorian/Aeolian, and Aeolian/Phrygian. Participants rated how well the ending "fit" the context. Two questions were of interest: (1) Do listeners give higher ratings to some modes (as endings) overall? (2) Do listeners give a higher rating to the ending if its mode matches that of the context? The results show a strong main effect of ending, with Ionian (major) and Aeolian (natural minor) as the most familiar (highly rated) modes. This aligns well with corpus data representing the frequency of different modes in popular music. There was also a significant interaction between ending and context, whereby listeners rated an ending higher if its mode matched the context. Our findings suggest that (1) our earlier "happiness" results cannot be attributed to familiarity alone, and (2) listeners without formal knowledge of diatonic modes are able to internalize diatonic modal frameworks.

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It is widely assumed that the perception of pitch organization—key, scale, harmony, and melody—is shaped by the listener's experience. Evidence for this is found in the classic work of Krumhansl (1990), where the perceived stability of pitches in a tonal context is strongly correlated with their frequency in musical corpora. Internalized scale frameworks play a role in many aspects of musical processing and response, including expectation (Schellenberg, 1997), tension (Bigand & Parncutt, 1999), and completeness (Palmer & Krumhansl, 1987). A question arises here, however: What kind of scale system is most appropriate for modeling this musical knowledge? Krumhansl's widely used tone profiles are based on the major/minor system of Western classical music. But present-day young adults—the population sampled in many music psychology experiments—listen to popular music much more than classical music, as recent studies have confirmed (The Echo Nest, 2015; Stratton & Zalanowski, 2003). If we wish to characterize the scale structures that are brought to bear in music perception, the classical major/minor system is not the only possibility and not necessarily the most appropriate one.

The study reported here examines the perception of diatonic modes—pitch structures that may reflect the experiences of many modern Western listeners better than classical scale structures. Before turning to the experiments and results, we will present an overview of diatonic modes and suggest how they might serve as a test case for studying more general issues of music cognition. We will also review a prior study on the "happiness" of diatonic modes, which partly motivated the current study.

DIATONIC MODES

Figure 1 displays six diatonic modes as scales, starting on the tonic of C.[1] Notice that each of these modes contains a particular ordering of five whole-steps (W) and two half-steps (H); collectively, they are displayed in Figure 1 from relatively sharpest to relatively flattest. The pitch organization of Western art music of the common-practice period is usually described not in terms of diatonic modes but in relation to major and minor keys. Diatonic modes and keys are related but not

[1] A seventh diatonic mode, Locrian, contains half-steps between the first and second scale degrees, and between the fourth and fifth scale degrees. It is the only diatonic mode that has a diminished fifth rather than a perfect fifth above the tonic. It is rarely found in either Western art music or popular music, and we did not include it in the studies discussed here.

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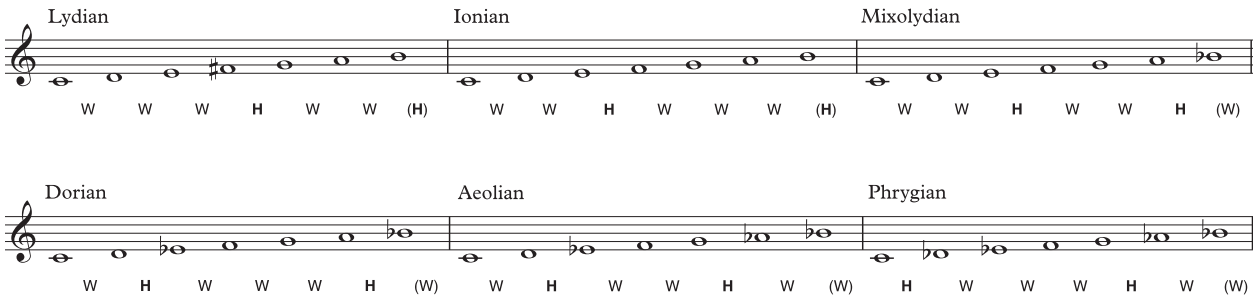

FIGURE 1. The six diatonic modes employed in this study with a fixed tonic of C. Whole (W) and half (H) steps indicated.

identical. In its scalar form, the major key shares the same pattern of half- and whole-steps as the Ionian mode. The minor key can be expressed through several different scalar orderings: natural minor, harmonic minor, and melodic minor; additionally, melodic minor differs in its ascending and descending form. Only natural minor and the descending melodic minor correspond to the Aeolian mode.

Diatonic modes are widely used in modern Western popular music (further evidence for this will be provided below); one need not have any specialized music training to encounter these pitch structures. The set of modes can therefore serve as a test case for studying more general issues of music cognition; namely the cognitive representation and implicit learning of scale hierarchies. Existing research has demonstrated the importance of learned scale structures for music perception in a range of systems and cultures, including classical major/minor scales (Krumhansl, 1990), North Indian ragas (Castellano, Bharucha, & Krumhansl, 1984), and Sami yoiks (Krumhansl et al., 2000). These studies have shown that listeners can quickly select the appropriate scale structure for a given stimulus. For example, in evaluating the "fit" of pitches, listeners respond quite differently to major contexts than to minor ones (Krumhansl, 1990). A study by Bartlett and Dowling (1988) offers further evidence that familiar scalar structures inform Western listeners' perceptions of melodies. The researchers found an asymmetry in the perceived similarity of melody pairs: when participants heard melodies in the order diatonic-nondiatonic, they perceived them as less similar than the same melodies in the reverse order (nondiatonic-diatonic). The authors posit that a diatonic melody evokes a small set of alternatives, among which the nondiatonic melody does not belong.

In the present study, we examine listeners' ability to discriminate among different scalar orderings of the diatonic collection within melodic contexts. We ask whether listeners can rapidly orient themselves to a diatonic modal framework and use it to evaluate subsequent melodic continuations. Our study also sheds light on the relative *familiarity* of different diatonic modes. Our interest in these issues stems partly from a previous study on the emotional connotations of modes, which we now describe.

"HAPPINESS" AND FAMILIARITY OF DIATONIC MODES

In an earlier study (Temperley & Tan, 2013), we investigated the perceived "happiness" of diatonic modes. It is widely accepted that major and minor keys have expressive implications, notably as "happy" and "sad," respectively, and experimental studies have confirmed this (Kastner & Crowder, 1990; Peretz, Gagnon, & Bouchard, 1998). Several theories have been put forth to explain these associations. Based on these theories and the relationship between modes and keys, we considered several predictions for the emotional connotations of diatonic modes. For instance, the "consonance" hypothesis predicts that modes with major tonic triads (Lydian, Ionian, Mixolydian) will be positively valenced, while those with minor triads (Dorian, Aeolian, Phrygian) will be negatively valenced. Another hypothesis, based on the "height" of modes relative to each other, predicts that modes will decrease in expressed happiness as flats are added (Lydian is happiest, Phrygian is least happy). Finally, we discussed the possibility that participants' happiness ratings would be influenced by their familiarity with each of the modes. This hypothesis predicts that Ionian would be perceived as the happiest mode, since it is (arguably) the most familiar. It should be noted that our 2013 experiment was specifically designed to probe emotional *recognition* rather than *induction*—the emotion that listeners perceived in the melodies, rather than the one that they felt while listening (Evans & Schubert, 2008; Gabrielsson, 2002). Familiarity has generally been found to influence felt rather than perceived emotion (Gaver & Mandler,

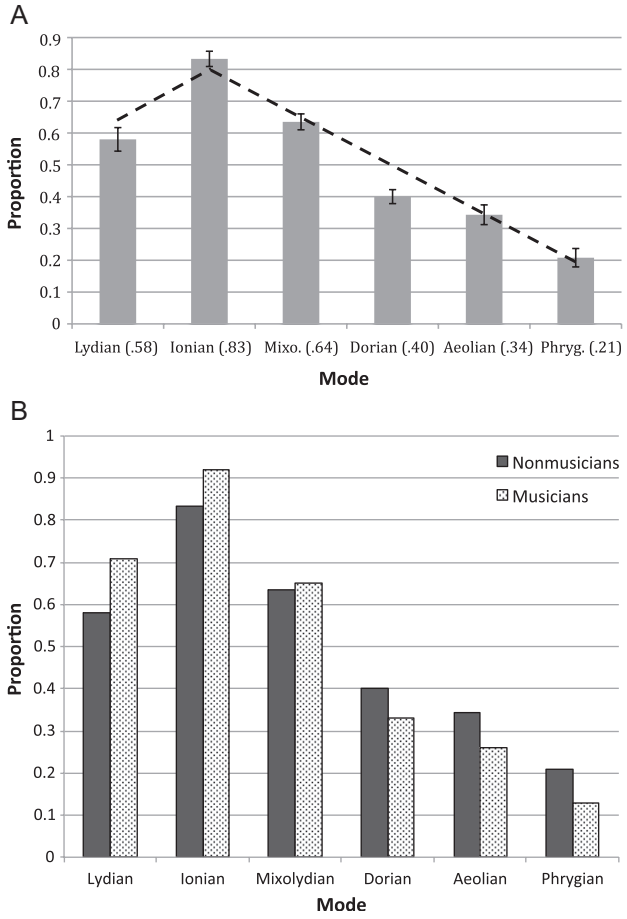

FIGURE 2. Overall "happiness" rating of each mode. (A) Temperley and Tan, 2013, Figure 10: The bar graph shows, for each mode, the proportion of trials involving that mode in which it was judged as happier. The dotted line shows the number of scale degrees each mode shares with Ionian. Error bars represent standard error. (B) Comparison of nonmusician and musician ratings for the same experiment.

1987; Schubert, 2013), but it is possible that felt emotions influenced listeners' judgments of emotional recognition. We discuss further evidence regarding the relative familiarity of different modes further below.

Participants in the 2013 study were University of Rochester students without any formal music training. In each trial, they heard two modal versions of the same melody and were asked to judge which of the two was happier. Our main finding is displayed in Figure 2a: the proportion of trials in which a particular mode was judged happier than its alternative decreased as scale degrees were lowered, with the exception of Lydian to Ionian. All but three pairwise differences—Lydian/Mixolydian, Lydian/Dorian, and Dorian/Aeolian—were significant. We conducted a similar experiment with music students at the Eastman School of Music and obtained a similar pattern of results, as shown in Figure 2b; in this case, all the pairwise differences were significant except Lydian/Mixolydian.

In this previous study, we assumed that in order to rate the emotional connotations of different modal melodies, listeners were implicitly differentiating among the diatonic modes. In the current study, we test this assumption. It is possible that, rather than hearing "in" modes, listeners were hearing each melody in a variant of the major key: that is, as a major-mode melody with chromatic notes. Indeed, as the dotted line in Figure 2a shows, the happiness of each mode corresponds fairly closely to the number of scale degrees it shares with major (or Ionian). In our 2013 discussion, we suggested using a probe-tone methodology to tease apart these two possible explanations. For instance, after hearing a Mixolydian context melody, listeners should judge the "fit" of a $\flat\hat{7}$ probe tone higher than $\hat{7}$ if they have internalized the modal framework. The opposite rating would suggest that listeners are hearing an underlying major-mode (or Ionian) framework that is undisturbed by $\flat\hat{7}$. We designed the present study with this methodology in mind.

A second question that arises from our previous study (Temperley & Tan, 2013) is whether familiarity can account for the significant differences in happiness ratings among modes. The use of modes in popular music is especially relevant here, since the subjects in our earlier experiment indicated that they listened to pop and rock music more than any other style. A number of authors have noted the importance of diatonic modes in popular music. It is generally agreed that Ionian, Mixolydian, Dorian, and Aeolian are commonly used in rock, while Lydian and Phrygian are rare (Biamonte, 2010; Moore, 2001; Stephenson, 2002; Temperley, 2001). (See Temperley, 2001, and Temperley & Tan, 2013, for examples of modal rock melodies.) This consensus view partly aligns with the data from Temperley and Tan (2013): as Figure 2 shows, Phrygian had the lowest happiness ratings, but Lydian had higher ratings than Dorian and Aeolian.

Corpus data offers further indirect evidence for the familiarity of modes. Figure 3 shows the overall distribution of scale degrees in a corpus of 66 rock melodies from 1980 to 2009 (Temperley, Waller, & de Clercq, 2015). Temperley and colleagues compiled the top 40 songs from *Rolling Stone* magazine's list of "500 Greatest Songs of All Time" and the top 40 songs from the same magazine's list of "Best Songs of the 2000s"; of these 80 songs, 14 contained no melody and were excluded. The remaining 66 songs include a range of popular styles, including pop, alternative and "indie" rock, heavy metal,

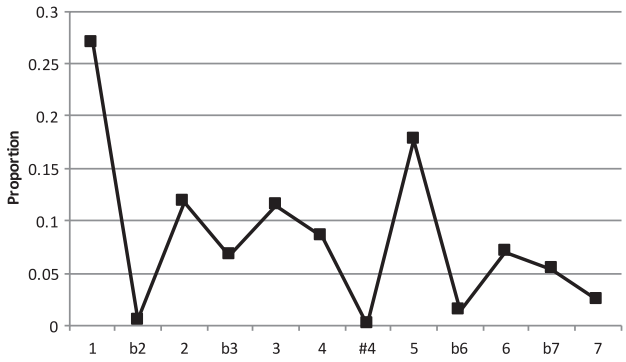

FIGURE 3. Scale-degree distribution in 66 rock melodies from 1980 to 2009 (66 songs). Songs taken from *Rolling Stone* magazine's "500 Greatest Songs of All Time" and the "Best Songs of the 2000s."

R&B, and adult contemporary. Figure 4 shows data for the same corpus, now with songs classified as "major" and "minor." Major songs were defined as those in which $\hat{3}$ occurred more often than $\flat\hat{3}$, and the reverse for minor.[2]

The "major" profile in Figure 4a reflects the major scale—the seven degrees of major are more prominent than the other five—but $\hat{7}$ appears with only slightly greater frequency than $\flat\hat{7}$; this suggests that Ionian is common in rock but so too is Mixolydian. In the minor profile (Figure 4b), the seven degrees that occur most frequently express the Aeolian mode. We should note that many rock melodies do not consistently adhere to any diatonic mode. Some melodies combine both $\flat\hat{3}$ and $\hat{3}$; others reflect pentatonic scales, blues-based scales, or still other scale structures. However, it seems fair to say that modal structures are at least implied in a large proportion of rock songs. Some melodies might be regarded as modal with chromatic alterations, just as classical melodies are often viewed as major or minor with some chromatic notes.

This corpus data suggests subtle but important differences between the scale frameworks of classical music and those of rock. In classical music, $\hat{7}$ is more frequent than $\flat\hat{7}$ in major and minor keys (Temperley, 2007; Temperley & Marvin, 2008). In the "major" rock profile in Figure 4a, $\hat{7}$ is more frequent than $\flat\hat{7}$ but only marginally so; in the "minor" profile in Figure 4b, $\flat\hat{7}$ is far more common than $\hat{7}$, quite unlike classical minor. Figure 4b also shows that $\flat\hat{6}$ is more common than $\hat{6}$ in the rock corpus. This aspect of the distribution is similar to that of classical minor (Temperley & Marvin, 2008), though it differs from the minor distribution of

[2] Temperley, Waller, and de Clerq (2015) marked modulations in the analyses and identified pitches in relation to the local key.

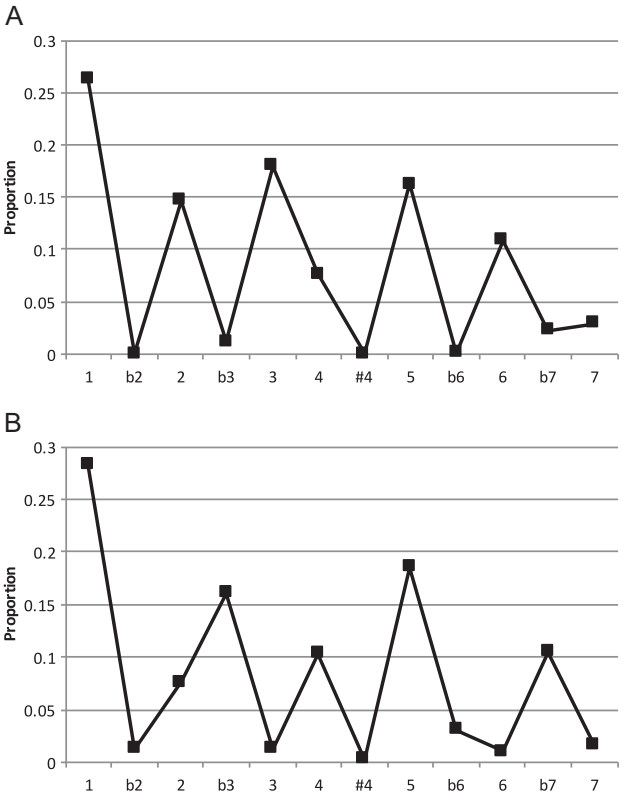

FIGURE 4. Scale-degree distribution for (A) "major" songs (with $\hat{3}$) from 1980 to 2009 (41 songs); and (B) "minor" songs (with $\flat\hat{3}$) from 1980 to 2009 (25 songs).

earlier popular music (1950–79), where $\hat{6}$ is more common than $\flat\hat{6}$ (Temperley et al., 2015).

Let us consider the corpus data in light of the 2013 "happiness" study. That $\flat\hat{2}$ and $\sharp\hat{4}$ are the least frequent scale degrees (see Figure 3) confirms the relative rarity of Lydian (the only mode containing $\sharp\hat{4}$) and Phrygian (the only mode containing $\flat\hat{2}$) within popular music. Our happiness data (Figure 2) partially accords with this finding, as Phrygian melodies were rated least happy overall. The Temperley, Waller, and de Clercq (2015) corpus contains more songs in the major category (41) than the minor category (25), suggesting that Ionian may be the most common mode in modern popular music. Again, this aligns with our happiness results, as participants rated Ionian melodies happiest. Notably, however, the corpus data (as a measure of familiarity) does not line up exactly with the happiness data. In particular, Figure 4b (minor profile) shows that Aeolian (with $\flat\hat{3}$ and $\flat\hat{6}$) is more common than Dorian (with $\flat\hat{3}$ and $\hat{6}$). If the happiness data reflected familiarity alone, the corpus results suggest that there should be a peak at Aeolian in Figure 2; instead, Dorian was rated

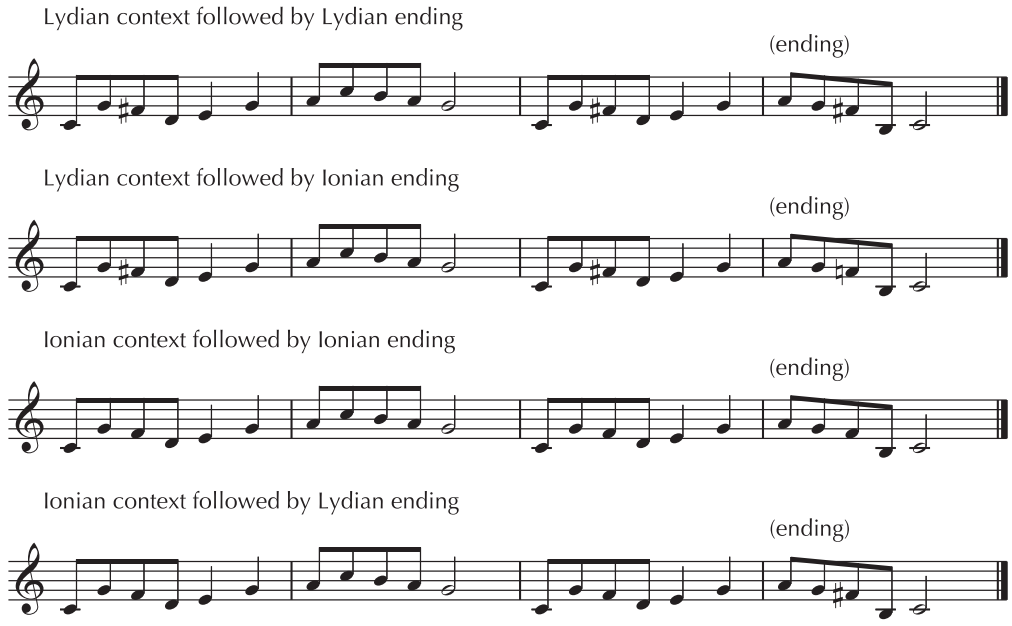

FIGURE 5. All four versions of one of the melodies used in the Ionian-Lydian experiment. Participants were placed into two groups, one that heard contexts in Ionian and the other that heard contexts in Lydian; both groups heard endings in both modes.

higher than Aeolian (though the difference was only significant for the musician subjects). Generally speaking, then, the corpus data offers limited support for the idea that familiarity plays a role in participants' judgments of conveyed happiness in modal melodies.

At the same time, corpus data is only an indirect way of studying the familiarity of modes. The group of experiments presented below was thus designed to investigate this issue more directly. In our Discussion, we will compare the results of the current study to the corpus data shown in Figure 4. We will also consider the results of the current study in relation to our 2013 study. If the results from this set of experiments align with the pattern shown in Figure 2, we could say with greater confidence that familiarity explains our happiness results. If our results do not align with the previous happiness data, we would have further evidence that other factors contribute to judgments of perceived emotions.

A "PROBE-MODE" APPROACH

In the present study, participants with minimal formal music training listened to diatonic melodies that contained a three-measure context in mode X or Y, followed by a one-measure ending in mode X or Y. On each trial, participants judged how well the melodic ending "fit" its preceding context. In devising melodies that began in one mode and ended in another, it was practical to limit our pairs of modes to those that differed by one scale degree (adjacent modes in Figure 1). The case of Ionian-Phrygian illustrates the difficulties of doing otherwise: in order to establish a Phrygian ending after three measures of an Ionian context, four new scale degrees would need to be introduced in the one-measure span. The case of Ionian-Lydian presents a less daunting compositional challenge; as Figure 5 demonstrates, only $\hat{4}$ needs to be altered to shift from one mode to the other. We designed four similar experiments, each comparing a different mode pair: Mixolydian and Ionian (MI), Ionian and Lydian (IL), Dorian and Aeolian (DA), and Aeolian and Phrygian (AP). Each participant completed two different experiments during a single session, either MI and DA or IL and AP. Thus each participant heard melodies in Ionian and Aeolian as often as melodies in two other modes.

Before discussing details of the four experiments, several possible outcomes are worth considering. First, an ending in mode X could produce higher "fit" ratings in a mode-X context than in a mode-Y context. Such a finding would suggest that participants were able to internalize the context mode. Given a Lydian ending in Lydian and Ionian contexts, for instance, the Lydian context would produce higher ratings if participants are listening "in" Lydian. Conversely, if participants rate a Lydian ending equally high in both Lydian and Ionian contexts, we would have evidence that participants did

not internalize the Lydian context and were instead hearing it as a major melody with ♯$\hat{4}$ inflections.

We can also consider the overall ratings for a given ending mode, across contexts. For instance, participants may rate all mode-X endings higher than mode-Y endings, regardless of context—that is, regardless of whether the ending mode matches the context mode. Such a result would suggest that our participants were more familiar with mode X than with mode Y. By extension, if the results of our 2013 happiness study represent listeners' familiarity with modes, the order of "fit" ratings in the current experiments should match Figure 2: Ionian endings would produce the highest fit ratings, followed in descending order by Mixolydian, Lydian, Dorian, Aeolian, and Phrygian. We acknowledge that other factors besides familiarity, notably psychoacoustic ones, could affect the overall fit ratings for different modal endings, and we will return to this possibility in our Discussion.

Method

PARTICIPANTS

Participants in the MI and DA experiments were 18 students from the University of Rochester (average age = 21, range = 18-25) and 12 students from Indiana University (average age = 20, range = 18-24). Participants in the IL and AP experiments were 16 students from the University of Rochester (average age = 20, range = 18-25) and 12 students from Indiana University (average age = 24, range = 18-35). None of the participants were music majors. University of Rochester participants reported an average of 1.5 years of private music lessons; none reported more than five years. Indiana University participants reported an average of 0.75 years of private music lessons; none reported more than three years. All participants were paid $10 for completing the study.

A post-test questionnaire asked participants whether they had ever learned about diatonic modes. No participants at Indiana University reported learning about diatonic modes. At the University of Rochester, two participants reported that they had. A follow-up question asked: "A melody using the C major scale with a tonal center of G would be in ___ mode." Neither participant was able to answer this question correctly. Participants were also asked if they had absolute pitch. Two of the Rochester participants and none of the Indiana participants reported that they did.

University of Rochester participants reported listening to an average of 12.6 hours of music per week, while Indiana University participants reported an average of 17.7 hours of music listening per week. A free-response question asked participants to name the styles of music to which they enjoyed listening. Among University of Rochester participants, the top three styles were "rock" (N = 18), "pop" (N = 14), and "classical" (N = 7). Among Indiana University participants, the top three styles were "pop" (N = 14), "rock" (N = 13), and "hip hop" (N = 10). In neither group did participants name any other style more than four times.

MATERIALS

We composed four melodies for each of the four experiments (each mode pair). All 16 appear in the Appendix. Using the notation software Sibelius, we generated MIDI sound files with a piano timbre. Using iTunes, we converted the resulting files to MP3 format. All melodies are four measures long in 4/4 time, with a three-measure context and a one-measure ending. The context and ending modes were varied systematically for each melody, producing four different versions; Figure 5 (above) provides an example. As we discuss in detail in Temperley and Tan (2013), ensuring that listeners hear the intended tonal center of a modal melody is a distinct compositional challenge. In the present study, all melodies (and all versions of each) have a tonal center of C, which we emphasize in several ways. C is the final note in every melody, and it also appears on the downbeats of measures 1 and 3. Each melody contains identical material in measures 1 and 3, and overall, there is durational emphasis on $\hat{1}$ and $\hat{5}$. We included a four-beat click-track at the beginning of each excerpt to encourage listeners to entrain to the 4/4 meter.

PROCEDURE

Participants were told that they would hear melodies containing four short phrases of approximately two seconds each. Their task was described as follows: "rate how well the 4th phrase (the end of the melody) fits with the rest of the melody." Participants sat at a Macintosh computer and used a web-based interface to initiate each trial. They only listened to each melody once. When the final measure ("4th phrase") began, the word "Ending" appeared on the screen. Participants were asked to rate the fit of the ending on a scale of 1 (*fits very poorly*) to 7 (*fits very well*), and they recorded their responses on paper.

Participants at each school and in each experiment were divided into two groups. One group heard contexts in mode X and endings in modes X and Y, and the other group heard contexts in mode Y and endings in modes X and Y. Each participant heard all eight trials (4 melodies x 2 ending modes) in two different and unique

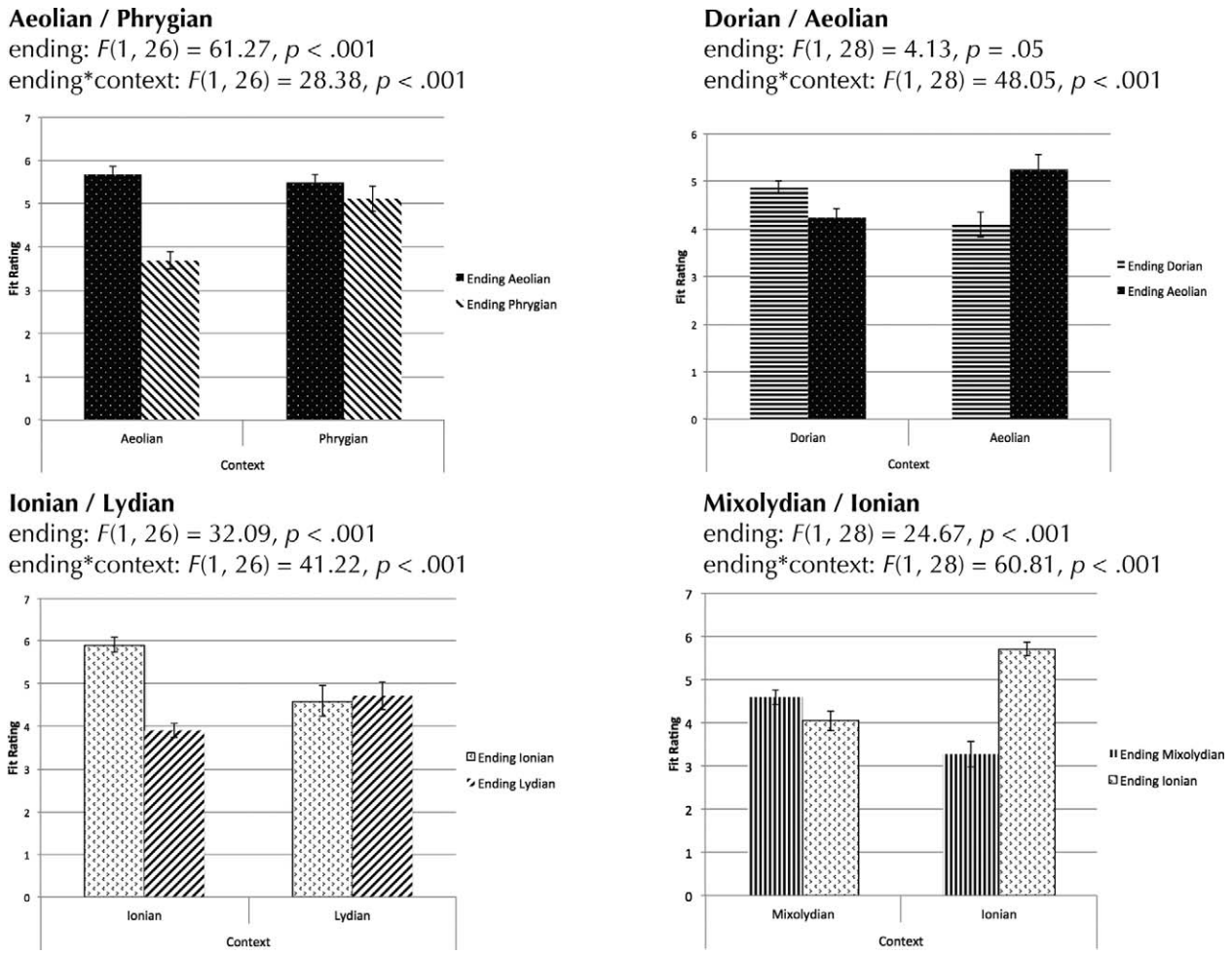

FIGURE 6. Results for each experiment. Each chart shows, for each modal context, the average "fit" rating for the two possible endings. Error bars represent standard error.

randomized orderings, resulting in 16 trials per experiment. Each participant completed two experiments, either DA and MI or AP and IL. Note again that participants heard music in Ionian and Aeolian just as frequently as the other two modes used in the experiment. At Indiana University, every participant completed one experiment (one mode-pair), took a break by watching a music video of their choice on YouTube, and then returned to the interface to complete a second experiment. At the University of Rochester, stimuli from two different experiments were intermixed, and participants took a YouTube break between the two blocks of 16 trials.

Results

In analyzing our data, we first conducted eight unpaired *t*-tests to compare the mean ratings of each modal ending by participants at the two schools. (Recall that each modal context was followed by one of two modal endings.) We found no significant differences between the mean ratings of University of Rochester students and Indiana University students, so we aggregated the data for the remaining analyses.

For each experiment, we ran a mixed ANOVA with three within-subject factors: phase (2: first eight trials, second eight trials), melody (4), and ending mode (2); there was one between-subject factor: context mode (2). Notably, there was a significant effect of ending mode, and a significant interaction between ending mode and context mode for each mode pair. Figure 6 displays the specific results for each experiment. In every case, an ending was rated higher if its mode matched the context mode than if it did not. And in all but one case, an ending whose mode matched the context mode was rated higher than an ending whose mode did not match

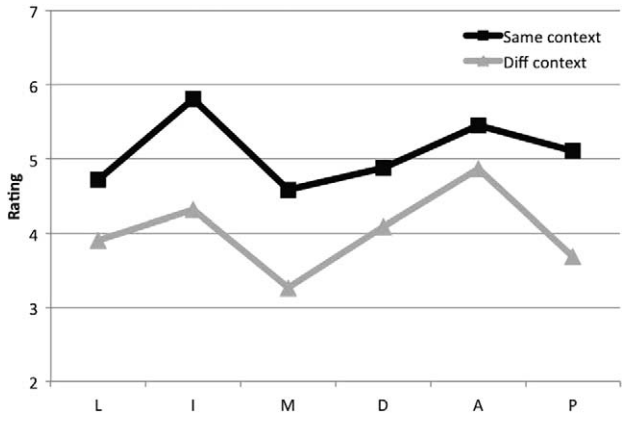

FIGURE 7. Average "fit" ratings for all six modal endings, for same and different contexts.

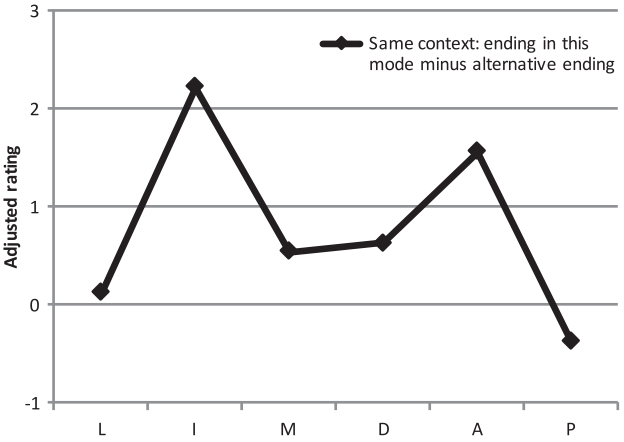

FIGURE 8. Strength of each mode in its context: (rating of ending X in context X) minus (rating of ending Y in context X).

the context mode. The exception lies within the Phrygian context (top-left quadrant of Figure 6); there, the Aeolian ending was rated higher than the Phrygian one.

Figure 7 shows the interaction of context and ending more clearly. The average rating for each modal ending is higher when the ending shares the same mode as the context (see the top, dark line) as opposed to when they are different (bottom, light line). Note, too, that participants rated Ionian and Aeolian endings highest among all conditions. This finding is even more pronounced in Figure 8. This figure shows the relative strength of each ending mode in its context; that is, each point is the difference between average ratings for an ending that matches the context and the alternative ending. For instance, given Lydian contexts, the difference in average ratings between Lydian endings and Ionian endings is 0.125. Given Ionian contexts, however, the difference in average ratings between Ionian endings and the two alternative endings (Lydian and Mixolydian) is much higher: 2.22. And for Aeolian contexts, the difference in average ratings between Aeolian endings and the alternatives (Dorian and Phrygian) is 1.56. This suggests that participants had clearer expectations for endings when they heard Ionian and Aeolian contexts than when they heard other modal contexts. Before leaving Figures 7 and 8, we note that they should be interpreted with caution, since they compare findings across experiments. We return to this issue in the Discussion below.

While the main effect of ending mode and the interaction of ending mode and context mode were our primary considerations, it also bears mentioning that there was a main effect of melody in all four experiments (see Appendix for the melodies). The average ratings for each melody in an experiment, across context modes and ending modes, fell within a narrow range. For AP and IL, the difference between the highest rated melody and the lowest rated melody was 0.7; for DA, this difference was 0.8, and for MI, the difference was 1.8. Nevertheless, the significant effects of melody suggest that regardless of mode, some context-ending pairs were perceived to fit better than others.

Discussion

Two main questions motivated the current study. First, we wondered whether college-age listeners would internalize the underlying scalar frameworks of melodies in diatonic modes. Second, we were interested in whether these listeners would demonstrate a greater familiarity with some modes over others; we hoped that this could shed light on our previous study of the emotional connotations of modes. We also wondered whether the fit ratings in this study, as a measure of familiarity, would align with the frequency of modes in recent popular music. We first address the issue of internalization and then turn to the issue of familiarity.

The significant interaction between context mode and ending mode provides evidence that listeners without any formal knowledge of diatonic modes can quickly orient themselves to a modal framework. In general, they perceived an ending to fit better when its mode matched the mode of the context. This is true even when the context was in Lydian, Mixolydian, Dorian, or Phrygian—modes that are relatively less common in Western classical music and popular music. Our initial concern that listeners in Temperley and Tan (2013) might have heard modal melodies as chromatically altered versions of major (or Ionian) is thus unsupported by the current study.

This finding connects in an interesting and complex way with other experimental research on the perception of pitch and scale. It reinforces the conclusion of prior studies that listeners are able to invoke an appropriate scale framework that is familiar to them from their experience (Bartlett & Dowling, 1988; Krumhansl, 1990; Krumhansl et al., 2000). However, other studies have found that to some extent, listeners are also able to adapt to novel scale structures. For example, Western listeners have some ability to judge the fit of tones within an Indian raga, after relatively brief exposure to it (Castellano et al., 1984). They can also internalize scales that are not widely used in any musical culture or ones that are newly created (Creel & Newport, 2002; Loui, Wessel, & Kam, 2010; Oram & Cuddy, 1995). Two of the modes in our experiment, Phrygian and Lydian, are relatively rare in popular music (as scholarly accounts and corpus data indicate), and listeners may have had little exposure to them. It is possible that when some participants heard Phrygian and Lydian melodies, they had no recourse to previously learned scalar frameworks and yet were able to extract statistical regularities from the melodic contexts. For other participants, however, melodies in Phrygian and Lydian might have invoked corresponding "learned" scale structures, perhaps depending on their musical experience. (Phrygian mode is relatively common in heavy metal music, for example; see Biamonte, 2010.) Further research is required to tease apart these two possibilities.

We also found a significant effect of ending mode in all four experiments, such that Ionian and Aeolian endings were rated higher than their adjacent modes. Moreover, Ionian endings received the highest fit ratings across all four experiments (see Figure 8). This result is consistent with the prevalence of the Ionian mode (equivalent to the major key) in Western classical music and popular music. The main effect of ending is also consistent with corpus data from Temperley et al. (2015) regarding the scale-degree distribution of recent popular music (Figure 4). Given the prevalence of $\flat\hat{6}$ (over $\hat{6}$) in "minor" popular music (Figure 4b), it is particularly notable that participants in the DA experiment (Figure 6, top-right chart) awarded stronger ratings to Aeolian than Dorian endings overall (combining both Dorian and Aeolian contexts). Recall, however, that in earlier popular music (1950-1979), $\hat{6}$ appears more frequently than $\flat\hat{6}$, even in minor songs (Temperley et al., 2015). With this in mind, a future study could replicate the Dorian/Aeolian experiment with an older generation of participants, or participants who are more familiar with earlier popular music.

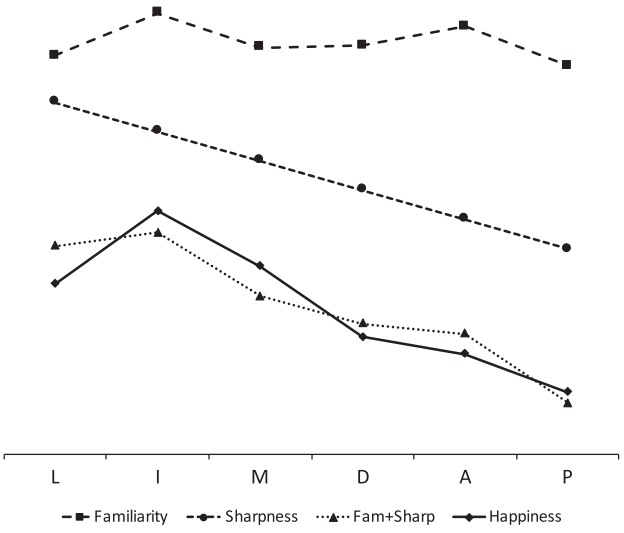

FIGURE 9. Adding a theoretical "sharpness" factor to the "familiarity profile" (from Figure 8) produces a series that is very similar to the "happiness" trend from Temperley and Tan (2013).

We now address the issue of familiarity as it relates to our study on the emotional connotations of modes (Temperley & Tan, 2013). If familiarity explained the results of that study, we could expect the ratings for the current study to resemble the "happiness" ratings in Figure 2. This is indeed the case if we compare the bottom charts in Figure 6 to the left half of the charts in Figure 2 (Lydian, Ionian, and Mixolydian); in the present study, Ionian clearly emerged as the higher-rated mode in the MI and IL experiments. But a comparison of the top charts of Figure 6 to the right half of Figure 2 suggests that familiarity alone cannot fully account for the results of the 2013 emotional-connotation study. Whereas in the earlier study, Dorian was rated relatively happier than Aeolian, in the current DA experiment, Aeolian endings were judged as better fitting than Dorian endings overall.

While familiarity may well play a role in explaining the 2013 happiness data, there is clearly another factor involved. We suggest that this factor associates greater happiness with modes that are "sharper"—that is, with raised, rather than lowered, scale degrees; Figure 9 demonstrates. The top line of the figure is taken from Figure 8, representing the overall familiarity of each mode as indicated by our experiments. To this "familiarity profile," we can add a linear "sharpness profile" (second line from the top). This results in a series ("Fam+Sharp") that closely resembles the happiness profile in Figure 2a; the happiness profile is also included in Figure 9 ("Happiness") for ease of comparison. The model presented in Figure 9 is only tentative,

and it should be taken with caution for several reasons. As we noted earlier, the familiarity values shown here are drawn from four experiments using a variety of different melodies. Recall, too, that the happiness profile in Figure 9 does not reflect direct judgments of happiness but rather the proportion of subjects choosing each mode as happier in forced-choice comparisons. These caveats notwithstanding, Figure 9 suggests that the happiness of modes could be predicted quite well as a combination of familiarity and sharpness.

If there is indeed a sharpness factor in the emotional connotations of modes, this raises the further question of how this factor can be explained. Huron, Yim, and Chordia (2010) suggested that scales involving relatively higher pitches are perceived as happier. This is possible, although in general, the factor of pitch height in music is not associated with valence (positive/negative emotion), but rather with arousal (energy/activity) (Gabrielsson & Lindström, 2001). An alternative explanation, which we favor, is that scale degrees are mentally represented in terms of fifth relations—the so-called *line of fifths*; see Figure 10. Scales that are further in the "sharp" direction on this line are perceived as happier. The line of fifths has indirect support from several other areas of music cognition, and it seems reasonable to suppose that it plays a role in emotional connotations as well.[3]

Returning to the results of our current study, we consider the possibility that other factors besides familiarity affected participants' ratings for ending modes. The overall preference for Ionian and Aeolian modes is reflected in Krumhansl and Kessler's (1982) probe-tone profiles; the seven degrees of Ionian (in a major context) and Aeolian (in a minor context) have the highest ratings. Several authors have argued that the probe-tone ratings are shaped primarily by corpus frequencies of scale degrees—that is, by familiarity (Krumhansl, 1990, p. 76; Huron, 2006). But a number of attempts have been made to model the Krumhansl-Kessler profiles using theoretical and/or psychoacoustic principles—for example, predicting a probe tone's fit by its strength as a "virtual pitch" in the preceding context (Parncutt, 2011), or by its spectral overlap with the pitches of the context (Milne, Laney, & Sharp, 2015). Such models can produce a close fit to the probe-tone data. To our knowledge, however, it has never been shown that these models predict privileged status for

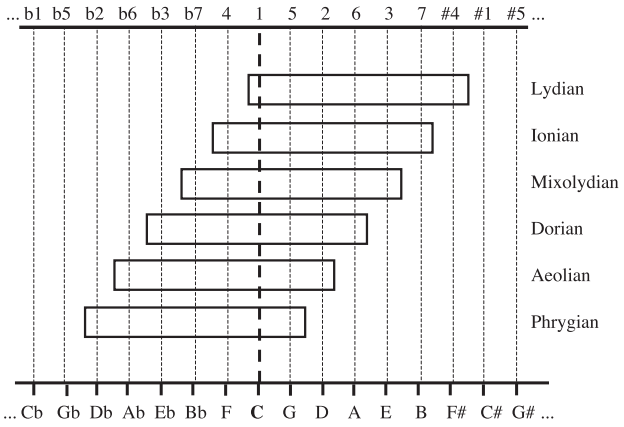

FIGURE 10. The "line of fifths." The top horizontal axis represents scale degrees; the bottom horizontal axis displays the corresponding pitch classes, assuming C as tonic. Rectangles indicate the scale degrees contained in each diatonic mode.

the Aeolian and the Ionian modes in relation to other diatonic modes. (The models are usually tuned to fit the Krumhansl-Kessler data by parameter-fitting, e.g., in Milne et al., 2015; it is possible that other parameter settings would fit other modes just as well or better.) We note, also, that the idea of Ionian and Aeolian as psychoacoustically privileged is not supported by historical and cross-cultural musical practice. Medieval theorists who codified modes of plainchant recognized Dorian, Phrygian, Mixolydian, and Lydian as the primary modes; only beginning in the mid-16th century were Aeolian and Ionian included in classifications. In popular music before 1980, Dorian was more common than Aeolian (as noted above); in Indian classical music, many scales are used, and Aeolian and Ionian are not especially privileged (Danielou, 1968). It nevertheless remains a possibility that the preference for Aeolian and Ionian modes is affected by factors other than familiarity; this deserves further exploration.

Our study involved four different experiments, each comparing a different pair of modes, and each experiment involved a different set of melodies (see Appendix). Comparing results across the four experiments should therefore be done with caution. (None of the statistical analyses reported in Figure 6 compare results across experiments.) It is possible that the melodies in one experiment were in some way better composed than those in another, which could cause ratings of the endings in one experiment to be higher overall, irrespective of mode. The effect of melody in all four experiments suggests that the details of the melodies did affect listeners' judgments. Each experiment also used a different pair of context modes, which no doubt affected the

[3] In Temperley and Tan (2013) we suggested using pentatonic scales to test which of the two theories, line-of-fifths or sharpness, offers a better explanation for perceived "happiness." The line of fifths theory predicts that major pentatonic is happier than minor pentatonic, while the height theory predicts the reverse.

ratings. Because of this, Figures 7 and 8 are suggestive only; one should be wary of concluding, for example, that Aeolian is more familiar than Mixolydian. In this study, we were most interested in comparing adjacent modes on the line of fifths—in particular, Dorian and Aeolian. Devising experiments to compare non-adjacent modes is a possible project for the future, though (as noted above) it might be difficult, using the current paradigm, to compare modes that differ by several scale degrees.

In designing melodies, we were also mindful of the differing melodic tendencies of modes, due largely to the location of half-steps. In Aeolian mode, the flattened sixth degree is a half-step above $\hat{5}$ and has a strong tendency to resolve to it; in Dorian, the raised sixth degree is a whole-step above $\hat{5}$, and its tendency to resolve downwards is much weaker. This may well affect the perceived "goodness" of different endings, irrespective of the context. We aimed to construct melodies in each experiment that contained a variety of scale-degree patterns; that is, we wanted to ensure that they would be convincing in both of the modes. For instance, in all four of our Dorian/Aeolian melodies $(\flat)\hat{6}$ moves down to $\hat{5}$ [$(\flat)\hat{6}$–$\hat{5}$ or $(\flat)\hat{6}$–$\hat{4}$–$\hat{5}$] as well as up to $\flat\hat{7}$ [$(\flat)\hat{6}$–$\flat\hat{7}$ or $(\flat)\hat{6}$–$\hat{1}$–$\hat{2}$–$\flat\hat{7}$]. In the Mixolydian/Ionian contexts, $(\flat)\hat{7}$ descends to $\hat{5}$ or $\hat{6}$ more frequently than it ascends to $\hat{1}$, but in the endings, $(\flat)\hat{7}$ ascends to $\hat{1}$ three out of four times; participants may have perceived a leading-tone effect in Ionian endings but not in Mixolydian endings. Thus despite our care, melodic contours may still have influenced ratings for adjacent modes. Future replications could consider other ways to control the "critical" scale degree within a melodic context.

Despite the above caveats, the current study supports the conclusion that Western listeners without music training are able to internalize diatonic modal frameworks. The study also reveals a pattern of familiarity of diatonic modes that accords well with their use in modern popular music. This familiarity pattern partly aligns with the results from a previous study on the perceived happiness of modes (Temperley & Tan, 2013), but it conflicts with the earlier results in one important respect—the case of Dorian versus Aeolian; this suggests that factors beyond familiarity influence the emotional connotation of diatonic modes. Altogether, diatonic modes offer a rich opportunity for studying the perception of pitch and scale, one that connects strongly with the experiences of modern Western listeners.

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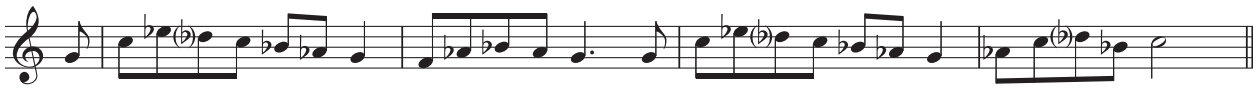
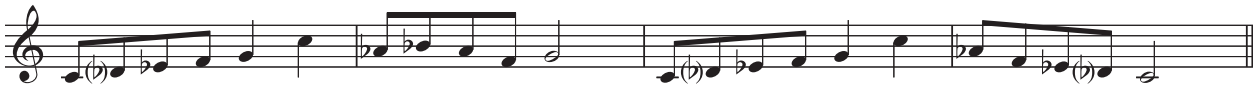
APPENDIX

Melodies Used in the Four Experiments

Aeolian/Phrygian 1



Aeolian/Phrygian 2



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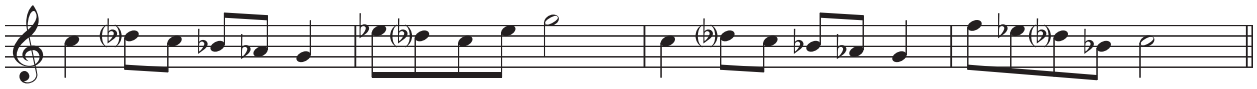
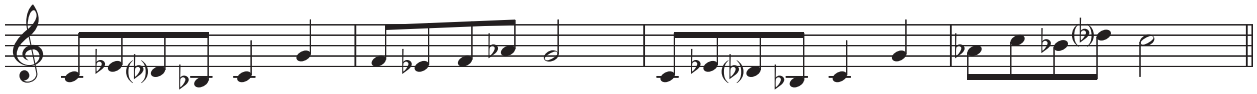
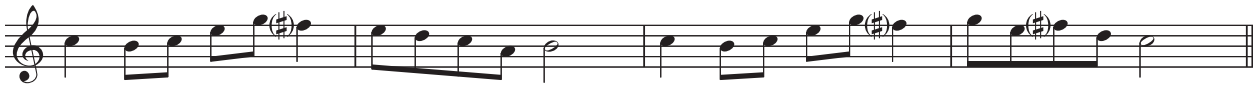


Aeolian/Phrygian 4



Ionian/Lydian 1



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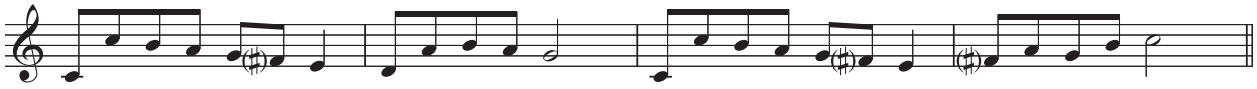

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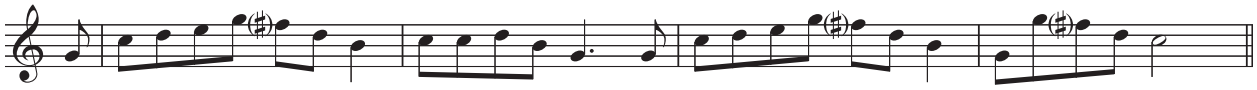

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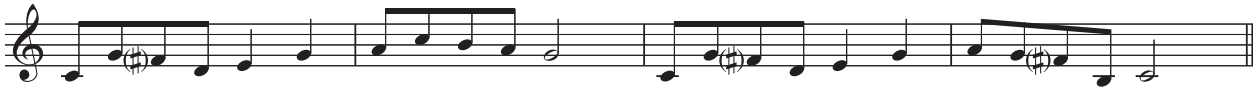
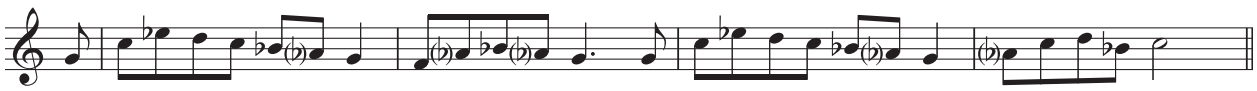


Dorian/Aeolian 1



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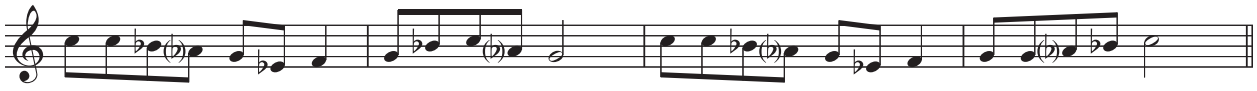
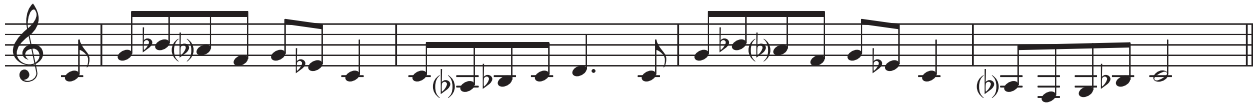
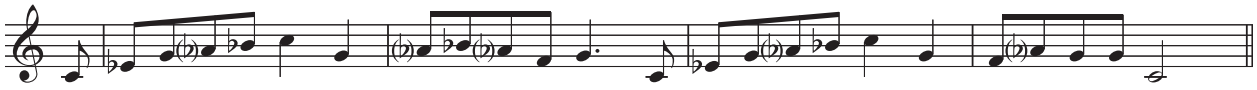


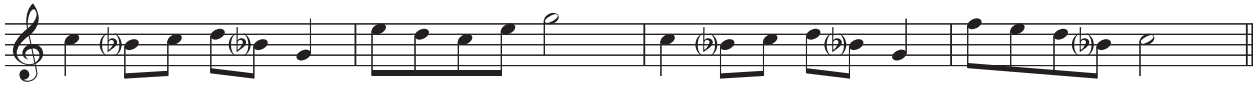
Dorian/Aeolian 3



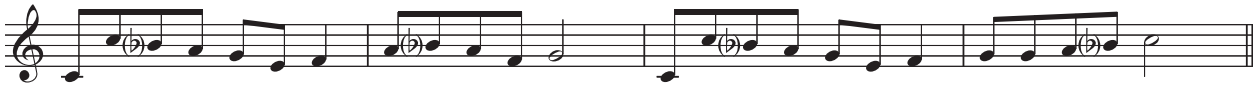
Dorian/Aeolian 4



Mixolydian/Ionian 1



Mixolydian/Ionian 2



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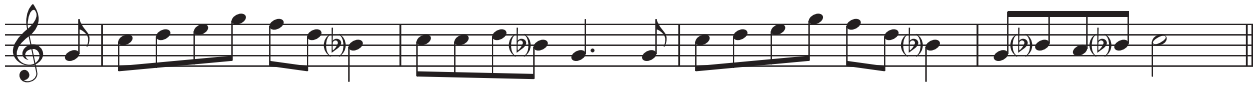

Mixolydian/Ionian 4