An ERP Study of Major-Minor Classification in Melodies

Andrea R. Halpern
Bucknell University

Jeffrey S. Martin and Tara D. Reed
University of Texas at Dallas

Composers commonly use major or minor scales to create different moods in music. Nonmusicians show poor discrimination and classification of this musical dimension; however, they can perform these tasks if the decision is phrased as happy vs. sad. We created pairs of melodies identical except for mode; the first major or minor third or sixth was the critical note that distinguished major from minor mode. Musicians and nonmusicians judged each melody as major vs. minor or happy vs. sad. We collected ERP waveforms, triggered to the onset of the critical note. Musicians showed a late positive component (P3) to the critical note only for the minor melodies, and in both tasks. Nonmusicians could adequately classify the melodies as happy or sad but showed little evidence of processing the critical information. Major appears to be the default mode in music, and musicians and nonmusicians apparently process mode differently.

Received November 10, 2006, accepted September 3, 2007.

Key words: mode perception, affective judgments, music training, ERP, late positive component

One of the primary functions of music is to convey emotion. This emotional message is often conveyed in music without words, implying that structural aspects of music, independent of linguistic content, carry emotional messages. Several musical aspects have been reliably associated with recognition of emotion by listeners, including tempo and mode. Faster tempos and major modes are often associated with happiness, and slower tempos and minor modes are associated with sadness (Crowder, 1985; Gagnon & Peretz, 2003). These associations emerge early in childhood, perhaps as young as three years (Kastner & Crowder, 1991).

We focus here on mode perception. The major or minor mode of a melody is determined by the set of pitches or scale from which the notes are selected; major and minor scales have only a few differences but are used widely by composers in many Western genres to convey affect, perhaps most obviously in classical pieces, but also in popular styles. Whissell and Whissell (2000) showed that Beatles tunes varied in mode depending on how negative or positive were the associated lyrics.

Despite the ubiquity of the major-minor distinction in music, and people's abilities to call major tunes "happy" and minor tunes "sad," research has shown that this distinction, paradoxically, is difficult for people to process. Halpern (1984; also Halpern, Bartlett, & Dowling, 1998) presented musicians and nonmusicians with melodies that had systematic changes in mode, rhythm, and contour. Pairs of melodies differing only in mode (but played in different keys) were rated as being highly similar, elicited confusions in an identification task, and were difficult to discriminate in a recognition task. Nonmusicians performed at chance levels on several of the accuracy tasks despite performing very well on rhythm or contour discrimination tasks. Even musicians showed less than perfect performance on this very straightforward task.

Leaver and Halpern (2004) found that nonmusicians performed at chance when discriminating a tune from its same-except-for-mode counterpart (played at a different pitch level) and improved to only a moderate level of performance after targeted training. Even musicians performed well below the ceiling level we expected. When asked to classify tunes as major or minor after a brief explanation and several examples with feedback, nonmusicians performed essentially at chance. However, nonmusicians could classify the same set of melodies as "happy" or "sad" quite well (as could musicians). After being instructed that major could be considered happy and minor could be considered sad, nonmusicians performed at a high level. Training consisting of learning how major and minor scales differed only increased classification success modestly. This pattern of results suggested that nonmusicians processed tunes quite differently depending on whether they were operating

Music Perception volume 25, issue 3, pp. 181–191, issn 0730-7829, electronic issn 1533-8312 DOI:10.1525/mp.2008.25.3.181

with more music theoretic or analytical set (listen for differences in pitches) or with an affective set (listen for the emotion). We had no information from that study whether musicians were also sensitive to this distinction, as we did not vary their instructions. Thus we did not know whether nonmusicians listening for emotional tone differences were processing the information in the same way as did the musicians.

In the current experiment, we turned to event-related potentials (ERPs) to help us find out whether musicians and nonmusicians differ in mode processing, even when performance is adequate among the latter. ERPs provide a fine-grained temporal analysis of the brain's response to stimulus evaluation, and they allow for assessment of different stages in information processing, from early sensory, mostly exogenous aspects of processing an acoustic stimulus, to more cognitive, endogenous aspects in information processing. Components that appear early in the ERP waveform, such as the N1 and P2 component, can be elicited even when subsequent cognitive processing of the stimulus is not required. Thus, they are often described as "onset" responses to the stimulus itself. In contrast, the P3 component, referred to hereinafter as simply a late positive component (LPC), can occur as late as 1000 ms after the event (Geal-Dor, Kamenir, & Babkoff, 2005). This response is often elicited in the "oddball" paradigm where listeners are asked to detect rare "target" events interspersed among frequent "nontarget" events. It reflects a decision about a contextually important stimulus or classification into task-relevant categories, rather than a response to the event itself (Dien, Spencer, & Donchin, 2004; Nieuwenhuis, Aston-Jones, & Cohen, 2005). Here, we focus on the LPC to examine the effect of task and musicianship in mode perception.

Although ERPs have been used to study processing of emotional tone in music (e.g., Schmidt & Trainor, 2001), we have located only one study that specifically looked at the neural basis for processing the musical mood devices of tempo and mode. Khalfa, Schön, Anton, and Liégeois-Chauvel (2005) presented four groups of classical music excerpts, comprising tunes that were fast and slow in major mode and the same in minor mode. Participants undergoing fMRI scanning had to classify each on a 5-pt scale of sadness to happiness. As has been found in other studies (Gagnon & Peretz, 2003), tempo dominated over mode in influencing the valence judgments. However, only the mode difference was reflected in a significant fMRI signal: subtracting major from minor melodies yielded activation in left frontal areas (BA 9 and 10) and bilaterally in the cingulate gyrus. Interestingly, major melodies did not engender any additional activation over that of minor melodies.

FIGURE 1. Example of a major and minor tune used in the study. Both melodies are identical until the circled note. This *critical note* is the first time the minor or major third of the scale appears.

In the current study, we took advantage of the fact that mode, although producing an overall effect in a piece of music, is created by a local selection of particular pitches. We wanted to know if we could capture the processing of mode at one point in time; specifically, the first time a diagnostic interval is sounded. Figure 1 shows two melodies identical except for mode. The first time they can be distinguished on mode is the circled note. This note, referred to hereinafter as the *critical note*, is the first instance where the minor or major third of the scale appears. Before that note is sounded, a mode judgment cannot be made; as soon as the note is sounded, the judgment can be made with 100% reliability. This property is a congenial one for an ERP study. We wanted to know if listeners would show an LPC to the critical note. To the extent they do, we can be confident that the judgment of the global property of mode, or mood, can be reduced to a decision at one point in time. We counted on the fact that although the critical note is neither an oddball nor incongruous, it is the point at which the "contextually important" decision can first be made about classification, and thus should elicit an LPC. We thought this pattern would vary as a function of two factors: the musicianship of the listener, and the classification task (major-minor, or happy-sad). Based on the results from Leaver and Halpern (2004), we expected that musicians would classify the tunes more accurately than nonmusicians. Among nonmusicians, we expected superior performance for the happy-sad task over the major-minor task. Our main hypotheses concerned the sensitivity of the LPC to the critical note. We predicted that if the musicians were using a music theoretical approach in analyzing the scale structure of the major and minor melodies, the critical note would elicit an LPC, reflecting a classification process close in time to perceiving the critical note. We thought that the happy-sad task for musicians would produce similar results to the major-minor task, as they would likely simply translate "happy" to major and "sad" to minor.

Nonmusicians on the major-minor task were not likely to do well. Thus, we anticipated no robust LPC to the critical note, thereby serving as a baseline control. However, their performance on the happy-sad task allowed for two competing predictions. Given that we expected moderately good performance from them, the presence of an LPC, even at a reduced amplitude or longer latency, would suggest that they were processing the critical note in a way qualitatively similar to the musicians, but perhaps less consistently, with less confidence, or more slowly. That would indicate that nonmusicians had a notion of scale construction and the important role of intervals in mode even if they could not verbalize this concept (implicit processing). On the other hand, adequate performance in the absence of an LPC to the critical note would indicate qualitatively different approaches to mode processing among nonmusicians and musicians, the nature of which could be pursued in future work.

Two other questions were of interest. Would the LPC be the same for major vs. minor melodies? Here we had no *a priori* hypothesis, because in information theory terms, the major and minor intervals were equally useful for the decision and we had equal numbers of major and minor tunes. But as will be seen later, the results of this analysis provided one of the most interesting outcomes of the study. Secondly, we can examine the distribution of the LPC over the scalp electrodes. Although many studies report symmetrical distribution, some do report lateralized effects (Geal-Dor, Kamenir, & Kabkoff, 2005). We located no previous work investigating lateral asymmetry in mode processing. However, given the well-established association of asymmetry favoring the right hemisphere with some aspects of music processing such as discrimination of pitch and timbre (Zatorre, Belin, & Penhune, 2002), we predicted that if any asymmetry were found, it would follow that same pattern.

Method

Participants

All 36 participants were right-handed, with no history of neurological illness or injury, and between the ages of 19 and 34. A pure-tone audiometric screening confirmed that hearing thresholds were normal in both ears (≤ 20 dB HL at octave frequencies between 500 and 8000 Hz). On average, the 18 musicians (7 males) had 16.2 years of formal education and 11.3 years of music training (range = 8 to 20 years). The 18 nonmusicians (5 males) had 15.7 years of formal education and 0.2 years of music training (range = 0 to 0.5 years). In order to ensure that major-minor instructions were not systematically influenced by affective labels, especially among the nonmusicians, half of each group received the major-minor task and half received the happy-sad task.

Materials

A set of 35 unfamiliar tunes comprised the initial stimulus set. These were newly composed or derived from obscure folk songs. Each, in our judgment, was unambiguously major or minor. For each of the tunes, we composed an other-modality twin (see Figure 1). The 70 tunes, synthesized in a piano timbre, were then presented in random order to three judges who were naïve to the purpose of the experiment and the construction history of the pairs. Each judge was proficient on at least one instrument and had studied music theory. The judges gave two ratings to each item: musicality, on a 1 (low) – 7 (high) scale, and majorness/minorness, using a scale where 1 = strongly major, 2 = weakly major, 3 = weakly minor, and 4 = strongly minor. Judges were allowed to use their own definitions of these terms for the ratings.

The judges agreed with one another on the modality ratings, and only on a few occasions erred in the assignment of modality. Upon being asked whether they noticed anything unusual about the set of 70 melodies, none of the three judges realized that each was repeated sometime in the list but in the opposite modality; one said she thought some of the tunes repeated exactly.

The 24 tune pairs in the final pool were selected such that on average they elicited very high and equal musicality ratings for the major and minor versions (M = 6.56 and 6.50, respectively), as well as for original and other-modality twin (M = 6.53 and 6.52, respectively). The average mode rating for major tunes was 1.10 and was 3.74 for minor tunes. Therefore, the final set of tunes was considered to be highly musical, equated on musicality for both modes and for originals and twins, and were highly representative of their respective modes. Of the 24 tune pairs, 11 were in C Major/Minor, 5 in D Major/Minor, and the rest were in the in keys of E, F, G, and A. Two-thirds of the tunes began on the tonic and the rest on the dominant of the scale. Tempo and meter also varied within the set of tunes. The important point here is that all aspects of the tunes other than mode, such as rhythm, length, contour, and interval distribution were equated between major and minor tunes.

For each tune pair used in the main experiment and practice, we determined the first note that indicated whether the tune was major or minor, or the critical note. For each tune pair used in the main experiment and practice, the critical note was usually the third degree of the scale, but occasionally was the sixth degree. The critical note of course occurred in the same position in each twinned melody, which was on average at note position 3.5, and on average 1.05 s from the beginning of the tune. All melodies were converted to WAV files, and some were truncated to make length more uniform across items. The sound files on average lasted 4.6 s. No feedback was given in the main task.

Procedure

Participants first filled out questionnaires about their musical background, handedness, and medical history involving neurological issues. A single loudspeaker and monitor faced the listener at a distance of 2.2 m. All melodies were presented at a comfortable loudness, approximately 60 dB-A as read on a sound level meter positioned at the location of the participant's head during testing.

In the happy-sad condition, participants were introduced to the idea that music can come in two "flavors" of happy and sad. They then heard an example of a major tune, which was called "happy" followed by its minor twin, called "sad." We did not explicitly refer to them as twins, but pointed out that the tunes were highly similar in some ways but differed in character. After a few more examples, the classification task was then explained. Seven practice trials ensued, with feedback. Instructions in the major-minor condition closely paralleled those in the happy-sad condition. No tunes in the practice phase were included in the main task.

For the main task, we instructed participants that each tune was to be classified using a response pad with two vertically aligned buttons labeled "major" and "minor," or "happy" and "sad." No information about proportion of major and minor tunes was offered. The buttons interfaced with the Stim^2 software (Stim^2, Compumedics Neuroscan, 2003), which recorded accuracy and response time information. Participants were also told to respond as soon as they had decided, but that accuracy was the more important criterion. The tune continued playing to the end even after a button press. Each tune was followed by 4 s of silence.

Listeners received all 48 items twice, for a total of 96 trials. These occurred in 8 blocks of 12 tunes, with time for rest in between each block. Each block was initiated by the participant. All tunes were heard once before they were repeated; no tune was followed closely by its other-modality twin. Instructions about rest breaks were presented on the monitor.

The classification task lasted about 20 min. Experimenters monitored the participant both visually via closed circuit television and by examining the ongoing EEG collected during the task. After completion of the session, participants were interviewed about what strategy they were using to make their decisions.

Electrophysiological Recording Techniques

Auditory ERPs were collected using the SCAN electrophysiologic data acquisition interface system (SCAN, Compumedics Neuroscan, 2003). Continuous EEG was recorded from 30 silver/silver-chloride electrodes mounted in an elastic cap affixed to the scalp according to a modification of the International 10-20 system. Electrode impedances were less than 10k ohms. Eye movements and blinks were monitored via two electrodes placed around the left eye in a transverse configuration. EEG channels were referenced to linked mastoid electrodes with a forehead electrode as ground. Ongoing EEG activity was sampled at 1000 Hz, amplified, analog filtered from 0.10 to 70 Hz, digitized, and stored for offline analysis.

Offline, individual epochs ranging from a 300 ms prestimulus interval (i.e., prior to the onset of the critical note) to 2,000 ms after the onset of the critical note were derived. Epochs were then linearly detrended, baseline corrected relative to the prestimulus interval, and digitally low-passed filtered at 20 Hz (−48 dB/octave). Epochs were rejected if the activity in the eye recording over the entire recording window exceeded $\pm$ 75 μV. Following artifact rejection, epochs were separately averaged to each stimulus type (major-minor). Individual averaged ERP waveforms were based on a minimum of 30 accepted epochs (Major tunes: $M = 35$ epochs, minor tunes: $M = 36$); approximately 27% of the data were rejected from further analysis.

Analysis of ERP Waveforms

The amplitude, latency, and morphology of individual ERP waveform components vary as a function of the location of the recording electrodes across the scalp. The N1 component, for example, is generally robust at central and fronto-central electrode positions; the LPC reaches a maximum over posterior areas, particularly at the parietal electrodes. In order to obtain an objective measure of component latency and amplitude for both group and individual ERP data, global field power (GFP) waveforms were derived (Skrandies, 1989, 1990). The GFP waveform is obtained by calculating, at each time sample over the analysis interval, the standard deviation of each voltage from a common average reference voltage. In essence, when these values are plotted as a function of time, peaks in the GFP waveform generally reflect the more robust ERP components across the electrode array.

The GFP transform was initially carried out on grand-averaged ERP waveforms in order to determine an approximate latency range of the LPC component (i.e., +/− 150 ms from the peak of the LPC from the GFP). LPC peak latencies for individual participants were derived over this same interval in a similar manner (i.e., from their GFP waveforms). To better characterize the maximum in the LPC response, topographic maps of the LPC were constructed using grand-averaged waveforms over the LPC latency interval obtained from the GFP. Based on the topographic distribution of the LPC, smaller subsets of electrodes were selected for statistical analysis of LPC amplitude. Specifically, four electrodes located over the left and right temporo-parietal regions (TP7/TP8, P7/P8, CP3/CP4, and P3/P4) were selected. This allowed for the assessment of hemispheric asymmetry of the LPC. To this aim, instead of selecting LPC peak amplitudes, we felt it more objective to generate LPC mean amplitudes over the LPC latency interval defined by the GFP waveform. Similarly, rather than selecting a single electrode for LPC analysis, data were averaged across the subset of electrodes positioned over each hemisphere to assess lateralization (e.g., left temporo-parietal region = TP7, P7, CP3, and P3 electrodes; right temporo-parietal region = TP8, P8, CP4, and P4 electrodes). Overall, while the GFP transform was used to select the appropriate LPC analysis interval, actual LPC mean amplitudes were obtained from the raw ERP data (prior to the GFP transform) for each individual. Although our principal focus was on the LPC, peak latencies and amplitudes for the N1 and P2 components were also obtained at a fronto-central electrode positioned along the midline (FCZ) characterizing the maximum of these components.

Results

Results were calculated using two ways of sorting the participants. First, we kept the four initial groups intact: musicians and nonmusicians, in both the happy-sad and major-minor task ($N = 9$ for each group). Post-test interviews revealed, not surprisingly, that six of the musicians in the happy-sad task reported using a major-minor strategy. Conversely, four of the nonmusicians in the major-minor task reported applying affective labels. Thus, by reported strategy, 15 musicians were in the major-minor group and 13 nonmusicians in the happy-sad group. We analyzed results by original and strategy groups. As outcomes changed very little, we mostly report data by original group membership.

Behavioral Findings

ACCURACY

Table 1 shows that musicians' average accuracy scores were quite high and nonmusicians' scores on the happy-sad task were moderately good. When the data for the nonmusicians were reanalyzed by behavioral strategy, accuracy of those nonmusicians who reported using a "happy-sad" strategy improved from 69% (grand mean; not shown in the Table) to 75%. The remaining nonmusicians, who did not discover a strategy, performed at chance (53%).

TABLE 1. Mean Accuracy Scores (in percent) for Musicians and Nonmusicians on the Major-Minor and Happy-Sad Task.

Group	Task	Major Tunes	Minor Tunes	Overall
Musicians	Major-Minor	97.6 (3.6)	89.7 (8.6)	93.6 (5.3)
	Happy-Sad	93.7 (4.5)	88.9 (8.4)	91.3 (4.5)
Nonmusicians	Major-Minor	63.0 (2.3)	66.1 (18.5)	64.6 (20.5)
	Happy-Sad	76.1 (9.5)	69.4 (5.1)	72.7 (6.8)

Note: Standard deviations are shown in parentheses.

Accuracy scores were subjected to an ANOVA, where participant group and task served as between-subject variables and type of tune served as a within-subjects variable. Analyses were performed on the raw proportions and also after arcsine transformation. Results were identical except in one instance noted below (we report raw proportions for clarity). Two main effects showed that musicians were superior to nonmusicians [92% vs 69%; $F(1, 32) = 39.60$, $p < .001$] and major tunes (83%) were superior to minor tunes [79%; $F(1, 32) = 8.99$, $p = .005$]. However, these findings are qualified by a significant group × task × tune type interaction, $F(1, 32) = 5.50$, $p = .025$ (in the transformed scores, the group × tune type interaction was also significant). A separate analysis for musicians showed only that major tunes (96%) were more accurately identified than minor tunes (89%), $F(1, 16) = 9.32$, $p = .008$. Nonmusicians showed a significant interaction between task and tune type, $F(1, 16) = 7.87$, $p = .013$. Major tunes were more accurately identified, but only on the happy-sad task (76% vs. 69%), $F(1, 8) = 8.84$, $p = .018$. Because accuracy rates varied among groups and conditions, and given the relatively few epochs available for analysis, all ERP analyses were based on all trials that were not rejected for artifacts. Also, we had no hypothesis for how the LPC would vary depending on correct or incorrect answers.

REACTION TIME

Reaction time (RT) was measured from the onset of the critical note to the button press. Because participants were told that accuracy was more important than speed, and the decision about when to press the button might be subject to various decisional criteria, we caution that RT's may not be easily interpretable for this task. Nevertheless, for completeness, we show in Table 2 the average of the median RTs. ANOVA results showed only a significant interaction between group and type of melody, $F(1, 32) = 12.38$, $p = .001$. Separate ANOVAs showed that musicians, on both the major-minor and happy-sad task, responded faster to minor tunes than major tunes (major-minor task: $F(1, 8) = 24.29$, $p = .001$; happy-sad task: $F(1, 8) = 13.90$, $p = .006$). No main effect of tune type was found for nonmusicians on either task. Musicians showed a nonsignificant tendency towards a speed-accuracy tradeoff ($r(16) = -.44$, $rcrit = .47$), whereas nonmusicians did not show any such hint ($r = -.03$).

Electrophysiological Findings

Figure 2 shows the grand-averaged ERP waveforms, triggered to the onset of the critical note, for musicians and nonmusicians to major and minor tunes. Since we found no main effect of task condition (major-minor or happy-sad) on LPC measures (see below), the data shown in Figure 2 have been collapsed across both tasks. Several aspects of Figure 2 are noteworthy. First, the N1 and P2 components (circled in figure) are most robust over frontal electrode sites. These components, however, do not differ appreciably between musicians and nonmusicians. N1 and P2 peak latencies and amplitudes at FCZ (the most prominent N1-P2 locus) were each subjected to an ANOVA, where group served as a between-subjects variable and type of melody served as a within-subjects variable. Results indicated no significant main effects or interaction, for N1 or P2. Second, irrespective of the task, musicians' responses to minor tunes evoked a robust LPC component over temporo-parietal electrode sites (circle in figure). For this group, the LPC response was observed over each hemisphere. Third, for both musicians and nonmusicians, LPC response was absent for the major tunes.

Similar information can be ascertained from inspection of the topographic distribution of the LPC component in all electrodes for musicians and nonmusicians as a function of the type of melody and task (Figure 3). Again, musicians show a robust LPC to minor tunes over the temporo-parietal region, irrespective of the task, which appears bilateral but asymmetric to the

TABLE 2. Mean Median Reaction Times (in ms) for Musicians and Nonmusicians on the Major-Minor and Happy-Sad Task

Group	Task	Major Tunes	Minor Tunes	Overall
Musicians	Major-Minor	2510 (1164)	1853 (1189)	2181 (1162)
	Happy-Sad	2608 (815)	2106 (814)	2357 (789)
Nonmusicians	Major-Minor	2563 (872)	2363 (916)	2463 (872)
	Happy-Sad	2702 (738)	2699 (610)	2743 (660)

Note: Standard deviations are shown in parentheses.

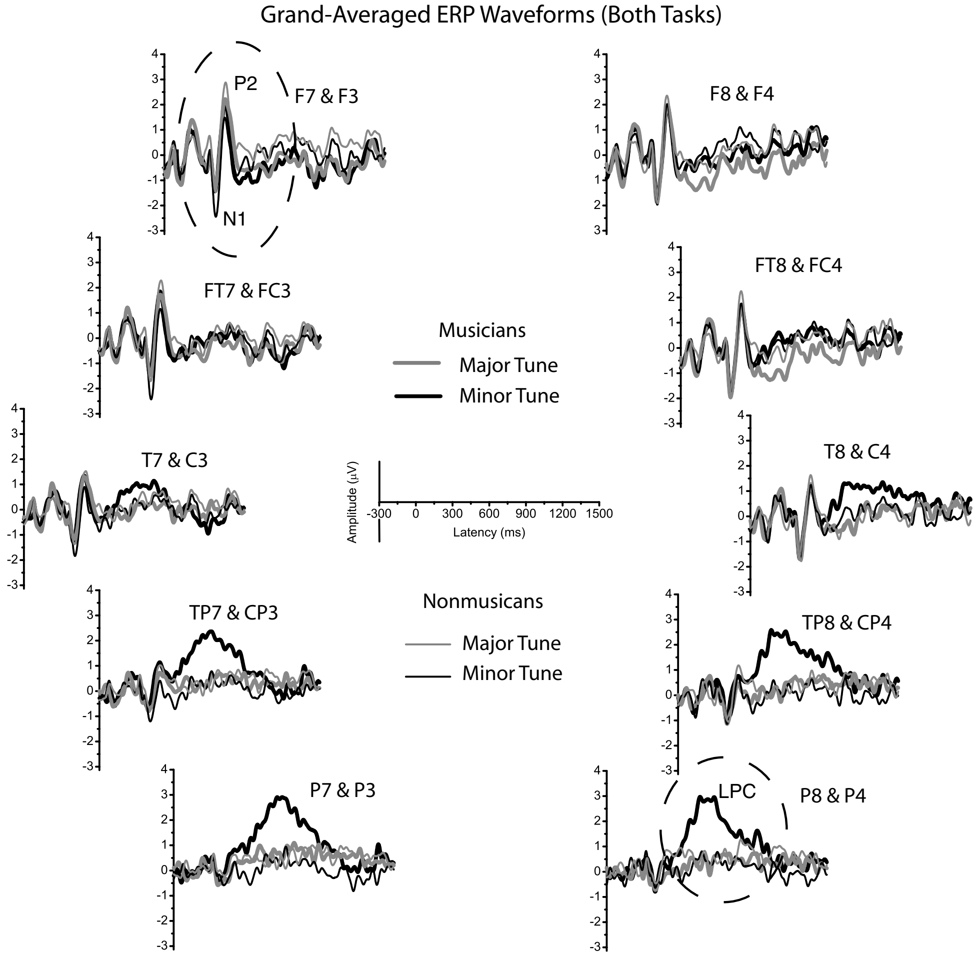

FIGURE 2. Grand-averaged ERP waveforms evoked to minor and major tunes for the musician and nonmusician groups. Data are collapsed across both task conditions (major-minor and happy-sad). Each waveform was constructed by averaging the data at two electrodes located over a scalp region (e.g., left frontal area = F7 and F3 electrodes). Both groups show a robust N1-P2 component to the onset of the critical note over frontal electrode sites (indicated by dashed circle). Only musicians show a robust LPC component to minor tunes for electrodes positioned over the temporo-parietal region, and slightly asymmetric to the right hemisphere (indicated by dashed circle).

right hemisphere. Nonmusicians, on the other hand, do not show a robust LPC component for either melody on either task.

Since the LPC was most prominent for musicians to minor tunes, for statistical purposes, a latency interval encompassing the LPC response was derived from the GFP transform using the grand-averaged data for this group. Again, the latency interval identified by the GFP was subsequently used to obtain LPC mean amplitudes at each of the electrodes characterizing the LPC response (i.e., left and right temporo-parietal regions) in individual raw ERP waveforms.

Figure 4 shows the GFP waveforms generated from the grand-averaged ERP waveforms for musicians and nonmusicians to the minor tunes. Again, data shown were collapsed across task conditions. From the figure, both groups show the expected exogenous responses to the critical note (i.e., N1 and P2); however, only the musicians shows a robust LPC signifying their classification of minor tunes. For the musicians, the LPC response extends up to 1000-1200 ms, but reaches a maximum over the 400-700 ms latency range. Based upon the GFP waveforms from individual musicians' responses to minor tunes, the average LPC peak latency was 537 ms ($SD = 62$ ms) on the major-minor task and 558 ($SD = 57$ ms) on the happy-sad task. The LPC latency range obtained across individual musicians, therefore, shows good agreement with the GFP waveform generated using grand-averaged ERP data (major-minor task: 555 ms, happy-sad task: 552 ms). Overall, a

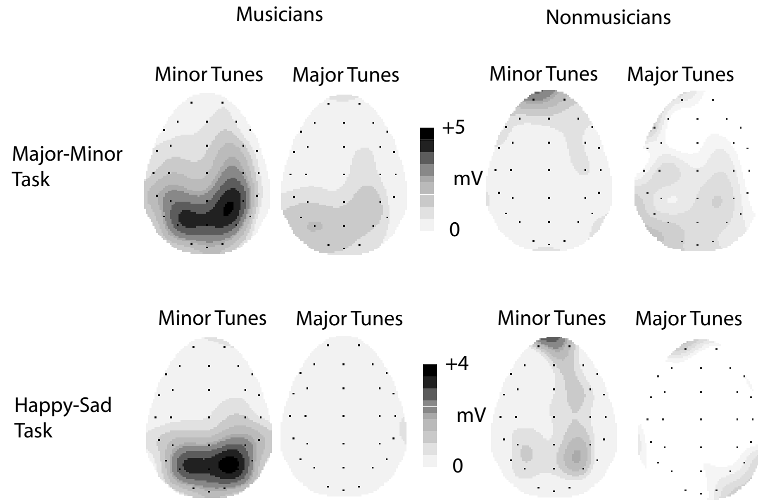

FIGURE 3. Topographic maps characterizing the LPC response. Musicians show a robust LPC to the minor tunes presented on both the major-minor and happy-sad tasks. Each map was constructed using the mean amplitude over 500-600 ms: a latency range approximately +/– 50 ms of the latency showing maximum amplitude in the GFP waveform (i.e., 550 ms) consistent with the LPC component observed to minor tunes for musicians. Differences in amplitude scales were selected in order to better characterize the maximum LPC response for each task. Nonmusicians do not show a robust LPC.

LPC latency interval from 400 to 700 ms was selected to examine differences between responses to major and minor melodies for each group.

To further substantiate whether the LPC was "present" or "absent" for each group, we compared individual mean amplitudes corresponding to the LPC latency interval to those obtained from the baseline prestimulus interval. Data were subjected to an ANOVA, where group and task served as between-subject variables and analysis interval (baseline, LPC), type of melody (major, minor), and electrode side (left hemisphere, right hemisphere) served as within-subjects variables. Results showed a significant interaction between analysis interval, type of melody, and participant group, $F(1, 32) = 7.59$, $p = .01$. No main effects of task, electrode side, or their interactions were significant. Although inspection of the topographic distribution of the LPC for musicians to minor tunes suggested an asymmetry to the right hemisphere (Figure 3), inspection of the individual data revealed that 6 out of 18 musicians showed either a symmetric or left-lateralized LPC. In separate ANOVAs, musicians showed a significant interaction between analysis interval and type of melody, $F(1, 17) = 26.37$, $p = .001$. Post hoc comparisons of each tune type showed that only the LPC mean amplitudes to minor tunes were indeed different from baseline, $F(1, 17) = 39.41$, $p < .0001$. For nonmusicians, no main effects or interactions were significant.

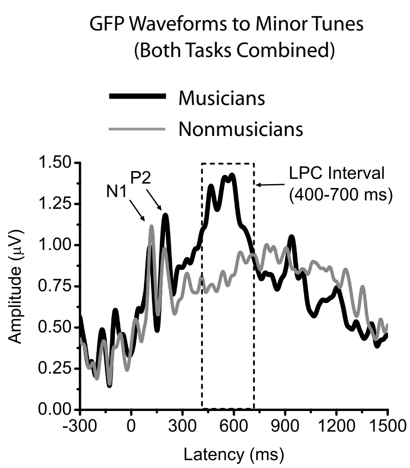

FIGURE 4. Global field power (GFP) waveforms generated from grand-averaged ERP waveforms to minor tunes for the musician and nonmusician groups. Data shown are collapsed across both tasks. Both groups show N1 and P2 components whereas only musicians show a robust LPC component to minor tunes, which reaches a maximum over the 400-700 latency range.

Finally, we examined the time course of the LPC response in musicians who reported using a "major-minor" strategy. Mean amplitudes were taken at 50 ms intervals from 300 to 900 ms for both minor and major tunes. The data were analyzed in an ANOVA, where interval type (12 successive 50-ms intervals), type of melody, and electrode position served as repeated measures. Results showed a significant interaction between the analysis interval and type of melody, $F(11, 154) = 3.97$, $p < .0001$. Post hoc analyses (with Bonferroni correction) revealed that mean LPC amplitudes for minor tunes differed from the response to major tunes between 450-600 ms. This analysis is consistent with the range of the LPC selected from the GFP analysis on the grand average data.

Discussion

The current results replicate the principal behavioral results from our previous study (Leaver & Halpern, 2004). Musicians in both studies were able to classify tunes reliably as major or minor, with about 90% accuracy. Nonmusicians who did not have affective labels available were unable to do this classification, and nonmusicians who either were told about affective labels, or discovered the labels themselves, showed moderately good performance. The ERP results considerably extend this behavioral profile to show the ways in which musicians and nonmusicians differ qualitatively, not just quantitatively, in how they do the task.

First, we note one way in which all participants were similar: the N1-P2 analysis showed no differences in amplitude or latencies between musicians or nonmusicians, for either major or minor critical notes; both groups showed robust N1 and P2 responses. A number of recent papers have looked at N1-P2 responses (or their magnetic equivalent) in musicians and nonmusicians. In these reports, musicians show enhanced early positive responses compared to nonmusicians. Results for early negative responses such as N1 or mismatch negativity are more variable, with some studies showing differences between musicians and nonmusicians and others not (Kuriki, Kana, & Hirata, 2006; Pantev, Oostenveld, Engelien, Ross, Roberts, & Hoke, 1998; Schön, Regnault, Ystad, & Besson, 2005; Shahin, Bosnyak, Trainor, & Roberts, 2003; Tervaniemi, Castaneda, Knoll & Uther, 2006).

Our task, however, differed from most of the above cited studies in several respects. First, most of them used a preattentive situation, in which tones or intervals were presented while participants were engaged in an unrelated task. Secondly, they tended to present single tones or intervals, or at most, very short melodies. Third, none of the studies used the kind of high-level classification task we used (Schön et al., 2005, asked for pleasantness judgments, but for 2-note intervals). It is possible that processing of tones embedded in an ongoing stream, to which the listener is attending in preparation for making the kind of global judgment we requested, has a less straightforward relationship to music training. Certainly all groups showed robust onset responses, allaying concerns that the nonmusicians had impaired early "sensory" processing of tones, which is important in the current context.

In contrast to this similarity, results for the LPC, which indexes more cognitive aspects of information processing, differentiated the groups. The melodies here were carefully selected to be identical to one another in every way except mode. On logical grounds, the critical note was the first place that listeners could distinguish major from minor; however, we could not in advance be sure that they would actually react electrophysiologically to this piece of information. In fact, our musicians showed a robust LPC at approximately 550 ms past the onset of this note. This response is consistent with their not only *registering*, but *using* the information in the critical note to make their decision (Nieuwenhuis, et al., 2005). Task instructions made no difference to the musicians, consistent with our predictions, as almost all of them reported converting our happy-sad instructions into a major-minor classification.

Perhaps the most surprising result was that the LPC response in musicians was entirely confined to the minor tunes. This is remarkable considering that in the local context of the experiment, the major and minor tunes were excruciatingly well matched. They had been judged as strong representatives of their respective modes and as being equally musical. Each tune had a twin in the opposite mode, so that length, tempo, rhythm, and all other parameters were equated. And the major and minor tunes occurred in equal proportion in the study. In information-theoretic terms, the critical note conveyed as much information for major as for minor tunes. Yet the ERP results seem to show that the musicians considered all the tunes major until they turned minor.

Why might major be the default classification or assumption for the musicians? All of our musicians had had extensive music training and should have been exposed to a great deal of music in the minor mode. Certainly instrumental musicians need to practice scales in both modes. But it is also true that at least several genres of music present major modes more often than minor. To document this, we consulted the HumDrum database (http://musiccog.ohio-state.edu/Humdrum/), which had several corpora of melodies available for consultation. They revealed a large preponderance of major key themes: 104 of 107 (97%) popular American songs, 35 of 35 (100%) American Barbershop songs, 4754 of 5358 (89%) German folk songs, and 7183 of 9806 (73%) instrumental classical themes.[1] Huron (2006) reported that when asked to

[1]We thank David Huron for providing this information.

imagine a chord, 94% of musician respondents imagined a major chord. So it seems that the musical environment may promote an anticipation that a melody or chord will be major, which may in turn derive from exposure. This result is also consistent with that of Khalfa et al. (2005), who found evidence of neural activity in their fMRI study only for minor and not major tunes. The brain seems to respond as if a minor melody is an oddball, not in the experimental session, but from life experience.

The nonmusicians, on the other hand, showed a dissociation between their behavioral performance and ERP response. We were not surprised that nonmusicians in the major-minor task lacked a LPC response: unless they discovered affective labels, the task would prove to be very difficult. More interestingly, even nonmusicians who were correct on three-quarters of the trials (the happy-sad group, plus the major-minor nonmusicians who used an affective strategy), showed no cognitive response (LPC) to the critical note, even at reduced amplitude or latency. It is possible that the 25% error rate was masking such a response, and that increasing the success rate, perhaps with additional training, would reveal at least some version of an LPC. On the other hand, it is possible that, whatever strategy nonmusicians were using did not involve extraction of the first-presented piece of useful information, at least within a second or so of its presentation. Perhaps they simply needed more information to make their decision, such as hearing a second occurrence of a critical third or sixth (21 of the 24 tune pairs had at least one more such interval). Two observations argue against this scenario. First, nonmusicians' reaction time was not slower than that of musicians (although the mapping from an ERP to a behavioral response may be complex and thus timing differences hard to interpret). Second, Leaver and Halpern (2004) found that nonmusicians' classification performance did not vary as a function of the number of major/minor thirds in the melodies. Nevertheless, a study in progress is examining ERP response to both the first and second critical notes in a set of melodies selected to have two critical notes.

Alternatively, nonmusicians may have processed the critical information, but in such a completely affective or global way that the LPC as a marker of a discrete decision point was decoupled from the behavior. Nonmusicians may have developed idiosyncratic reactions to the melodies or consulted irrelevant information, such as contour or tempo, to help them make their decision. In this context, it is interesting that several nonmusicians, when asked about their strategy, thought the happy (or major) melodies were faster than the minor, which was of course illusory. One nonmusician, apparently associating mode with a spatial dimension, thought she had discovered that major melodies were coming out of the top of the speaker and minor from the bottom of the speaker!

The final point concerns the lack of lateralization pattern in this study. Although our topographic map appeared to show a right-sided lateralization for the musicians classifying minor tunes (the only situation in which we had a significant LPC), and about 2/3 of the musicians did show asymmetry of LPC response to the right, statistical analyses using side of electrode failed to support a group difference. We also note that Khalfa et al. (2005) localized the activity involved in mode perception (minor melodies) to the left frontal area. As their task was a classification on valence, equivalent to our happy-sad task, we must await studies that employ electrophysiological and neuroimaging techniques in the same study to help resolve the issue of localization of mode processing.

Author Note

We thank Dr. James Jerger for generously allowing use of his facilities for the ERP testing and Brittney McGill for preparing stimulus materials.

Correspondence concerning this article should be addressed to Andrea Halpern Psychology Department, Bucknell University, Lewisburg, PA 17837. E-MAIL: ahalpern@bucknell.edu

References

CROWDER, R. G. (1985). Perception of the major/minor distinction: III. Hedonic, musical, and affective discriminations. *Bulletin of the Psychonomic Society, 23*, 314-316.

DIEN, J., SPENCER, K., & DONCHIN, E. (2004). Parsing the late positive complex: Mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology, 41*, 665-678.

GAGNON, L., & PERETZ, I. (2003). Mode and tempo relative contributions to "happy-sad" judgments in equitone melodies. *Cognition and Emotion, 17*, 25-40.

GEAL-DOR, M., KAMENIR, Y., & BABKOFF, H. (2005). Event-related potentials and behavioral response: Comparison of tonal stimuli to speech stimuli in phonological and semantic tasks. *Journal of Basic Clinical and Physiological Pharmacology, 16*, 139-155.

HALPERN, A. R. (1984). Perception of structure in novel music. *Memory and Cognition, 12,* 163-170.

HALPERN, A. R., BARTLETT, J. C., & DOWLING, W. J. (1998). Perception of mode, rhythm, and contour in unfamiliar melodies: Effects of age and experience. *Music Perception, 15,* 335-356.

HURON, D. (2006). *Sweet anticipation: Music and the psychology of expectation.* Cambridge, MA: MIT Press.

KASTNER, M. P., & CROWDER, R. G. (1991). Perception of the major/minor distinction: IV. Emotional connotations in young children. *Music Perception, 8*, 189-201.

KHALFA, S., SCHÖN, D., ANTON, J. L., & LIÉGEOIS-CHAUVEL, C. (2005). Brain regions involved in the recognition of happiness and sadness in music. *Neuroreport, 16*, 1981-1984.

KURIKI, S., KANDA, S., & HIRATA, Y. (2006). Effects of musical experience on different components of MEG responses elicited by sequential piano-tones and chords. *Journal of Neuroscience, 26,* 4046-4053.

LEAVER, A. M., & HALPERN, A. R. (2004). Effects of training and melodic features on mode perception. *Music Perception, 22,* 117-143.

NIEUWENHUIS, S., ASTON-JONES, G., & COHEN, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin, 131*, 510-532.

PANTEV, C., OOSTENVELD, R., ENGELIEN, A., ROSS, B., ROBERTS, L. E., & HOKE, M. (1998). Increased auditory cortical representation in musicians. *Nature, 392*, 811-814.

SCAN (2003). [Computer software and hardware]. El Paso, TX: Compumedics Neuroscan.

SCHMIDT L. A., & TRAINOR, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes *valence* and *intensity* of musical emotion. *Cognition and Emotion, 15,* 487-500.

SCHÖN, D., REGNAULT, P., YSTAD, S., & BESSON, M. (2005). Sensory consonance: An ERP study. *Music Perception, 23,* 105-118.

SHAHIN, A., BOSNYAK, D. J., TRAINOR, L. J., & ROBERTS, L. E. (2003). Enhancement of neuroplastic P2 and N1c auditory evoked potentials in musicians. *Journal of Neuroscience, 23,* 5545-5542.

SKRANDIES, W. (1989). Data reduction of multichannel fields: Global field power and principal components analysis. *Brain Topography, 2,* 73-80.

SKRANDIES, W. (1990). Global field power and topographic similarity. *Brain Topography, 3,* 137-141.

STIM^2 (2003). [Computer software and hardware]. El Paso, TX: Compumedics Neuroscan.

TERVANIEMI, M., CASTANEDA, A., KNOLL, M., & UTHER, M. (2006). Sound processing in amateur musicians and nonmusicians: Event-related potential and behavioral indices. *Neuroreport, 17,* 1225-1228.

WHISSELL, R., & WHISSELL, C. (2000). The emotional importance of key: Do Beatles songs written in different keys convey different emotional tones? *Perceptual and Motor Skills, 91,* 973-980.

ZATORRE, R. J., BELIN, P., & PENHUNE, V. B. (2002). Structure and function of auditory cortex: Music and speech. *Trends in Cognitive Sciences*, *6*, 37-46.