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Ear Advantage for Musical Location and Relative Pitch: Effects of Musical Training and Attention

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Abstract
Trained musicians have been found to exhibit a right-ear advantage for high tones and a left-ear advantage for low tones. We investigated whether this right/high, left/low pattern of musical processing advantage exists in listeners who had varying levels of musical experience, and whether such a pattern might be modulated by attentional strategy. A dichotic listening paradigm was used in which different melodic sequences were presented to each ear, and listeners attended to (a) the left ear or the right ear or (b) the higher pitched tones or the lower pitched tones. Listeners judged whether tone-to-tone transitions within each melodic sequence moved upward or downward in pitch. Only musically experienced listeners could adequately judge the direction of successive pitch transitions when attending to a specific ear; however, all listeners could judge the direction of successive pitch transitions within a high-tone stream or a low-tone stream. Overall, listeners exhibited greater accuracy when attending to relatively higher pitches, but there was no evidence to support a right/high, left/low bias. Results were consistent with effects of attentional strategy rather than an ear advantage for high or low tones. Implications for a potential performer/audience paradox in listening space are considered.

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Highly trained musicians exhibit greater accuracy in reporting musical sequences in a dichotic listening task if higher pitched tones are presented to the right ear and lower pitched tones are presented to the left ear (Deutsch, 1985; see also Ivry & Lebby, 1993). This pattern is consistent with observations that musicians often configure themselves with higher pitched instruments stage right and lower pitched instruments stage left, given that such an arrangement would optimize performing musicians' perception of music in the context of a high pitch/right ear, low pitch/left ear processing advantage. However, if such ear advantages also occur in individuals who are not highly trained in music, then a performer/audience paradox exists in which an audience receives musical stimuli in a configuration opposite to that received by musicians (i.e., high pitches on the left and low pitches on the right; Deutsch, 1987, 1999). In such a scenario, either the listening experience of the performers or the listening experience of the audience—but not both—could be optimized within a traditional stage and audience listening space.

Confirmation of a performer/audience paradox has important implications for design of performance spaces and configuration of onstage instrumentation. However, it is unclear whether ear advantages similar to those of highly trained musicians in Deutsch's (1985) study exist in individuals who are not musically trained, and if so, whether such ear advantages might be compensated for, or influenced by, focusing attention on different aspects of musical stimuli. Accordingly, the experiments reported here examined whether ear advantages for high tones or low tones occurred in individuals who were not musically trained and whether any such ear advantages were influenced by attentional strategy.

The existence of ear advantages such as those reported by Deutsch (1985) suggests possible cerebral asymmetries in the processing of musical stimuli. In an early study, Bever and Chiarello (1974) found that musicians exhibited better recognition for melodies presented to the right ear, indicating left hemisphere dominance, and that nonmusicians exhibited better recognition for melodies presented to the left ear, indicating right hemisphere dominance. Likewise, Johnson (1977) presented violin melodies in a dichotic listening task and found a right-ear advantage for musically trained participants and a left-ear advantage for participants not trained in music. Bever and Chiarello concluded that musicians were more likely to analyze music (i.e., break down music into its components rather than hearing it as a gestalt) while listening, and that such analyses required greater information processing within the left hemisphere (but see Burton, Morton, & Abbess, 1989; Wagner & Hannon, 1981). Consistent with this, Peretz and Morais (1980) reported that participants who used an analytic strategy were more likely to exhibit a right-ear advantage (see also Peretz, Morais, & Bertelson, 1987). Mazziotta, Phelps, Carson, and Kuhl (1982) used positron emission tomography to investigate analytic strategy in a tonal memory task. They reported that participants who used an analytic strategy in a tonal memory task exhibited greater glucose metabolism in the left cerebral hemisphere during the task, whereas participants who used a nonanalytic strategy exhibited greater glucose metabolism in the right cerebral hemisphere during that same task. These findings suggest that left-lateralized brain activity is associated with analytic strategy for musical stimuli. This evidence supports the hypothesis that a right-ear advantage is modulated by specific cognitive strategies.

Some studies have specifically focused on ear-advantage effects for musical stimuli in listeners without extensive training or experience in music. Hoch and Tillman (2010) presented sequences of musical chords (four simultaneous notes) or sequences of spoken syllables (four simultaneous voices; two male and two female) to nonmusicians, and listeners identified the timbre of the final chord or the identity of the final syllable. Participants exhibited greater accuracy in identifying the musical structures that were presented to the left ear. Izumi et al. (2011) reported transient signal change in the blood-oxygen-level-dependent functional magnetic resonance imaging (fMRI) response in the left hemisphere of nonmusicians when musical sounds were presented. They suggested that left hemisphere musical processing was analogous to right hemisphere language processing.

In contrast, in a meta-analysis of positron emission tomography and fMRI data unspecified for musical experience, Schirmer, Fox, and Grandjean (2012) reported relatively equal engagement of left and right hemisphere structures in response to speech or music. Schönwiesner, Rübsamen, and von Cramon (2005) used stimuli created to mimic properties of both language and music while directly resembling neither. Results from fMRI analyses suggested that such spectral information resulted in more left hemisphere activation and temporal information resulted in more right hemisphere activation. More recently, Okamoto and Kakigi (2013) used magnetoencephalography while varying click trains along either spectral or temporal dimensions. They found that differences in spectral information resulted in more right hemisphere activation, whereas differences in temporal information resulted in more left hemisphere activation; furthermore, differences in mismatch negativity suggested that differences in processing occurred prior to the effects of attentional modulation. The patterns of cerebral asymmetries in Okamoto and Kakigi's and in Schönwiesner et al.'s studies are directly conflicting. It might be that different types of auditory stimuli used in these experiments evoked different responses. Given that spectral information contributes to consonant and vowel recognition more than does temporal information (e.g., Xu, Thompson, & Pfingst, 2005), one possibility is that Schönwiesner et al.'s stimuli evoked a different mode of processing more typical of language than the (nonlanguage-like) click trains used by Okamoto and Kakigi. To the extent that musicians process music in a more analytic or language-like way (cf. Bever & Chiarello, 1974), cerebral asymmetries between musicians and nonmusicians could be predicted based upon stimulus type and attentional strategy.

Given potential differences in cerebral asymmetries in processing musical stimuli exhibited by musicians and by nonmusicians (e.g., Bever & Chiarello, 1974; Johnson, 1977), and potential differences in hemispheric asymmetries of listeners using analytic or nonanalytic strategies (e.g., Burton et al., 1989; Mazziotta et al., 1982; Peretz & Morais, 1980), it is possible that the performer/audience paradox would not occur, as musicians and nonmusicians could each optimize their perception of music by using different attentional strategies.[1] However, even though attentional strategy can influence cerebral processing in dichotic presentation of musical stimuli (Hugdahl et al., 1999, 2000; see also Carlyon, Cusack, Foxton, & Robertson, 2001), the extent to which attentional strategy influences a potential ear advantage or cerebral asymmetry in processing of pitch is not yet known. The experiments reported here examined this issue by directing selective attention toward different aspects of musical stimuli within a dichotic listening task. In Experiment 1, participants directed attention toward a musical stream in the left or right ear and indicated the direction of successive pitch transitions within the attended stream. In Experiment 2, participants directed attention toward a stream of higher or lower tones, regardless of ear of presentation, and indicated the direction of successive pitch transitions within the attended stream.

Experiment 1

Experiment 1 was conducted as an extension of Deutsch's (1985) study on cerebral asymmetries in musical processing, utilizing an experimental framework similar to that of Deutsch. However, we used a novel response method that allowed participation of both musically trained participants and musically untrained participants. Specifically, participants were presented with brief musical stimuli and indicated whether each tone-to-tone transition moved upward or downward in pitch (see Figure 1). We hypothesized that if musically untrained participants exhibit the same ear advantages (and presumably the same underlying cerebral asymmetries) that Deutsch found in highly trained musicians, then we would find a right-ear advantage for high tones and a left-ear advantage for low tones for these participants. Specifically, we predicted that judgments of the direction of pitch movement between successive tones that involve high or low pitches should be facilitated (i.e., more accurate) when those pitches are presented to the right ear or to the left ear, respectively. However, studies that indicate significant differences in processing patterns (e.g., Bever & Chiarello, 1974; Johnson, 1977) or analytic strategies (e.g., Burton et al., 1989; Wagner & Hannon, 1981) suggest that musically untrained participants will not exhibit the same ear advantages for musical stimuli as musically trained participants. If this were the case, we would fail to see more accurate responses when high tones were presented to the right ear and when low tones were presented to the left ear.

Method

Participants

Nineteen undergraduates participated in return for partial course credit. Seven participants (all right-handed) were upper level undergraduates in a university music department; these

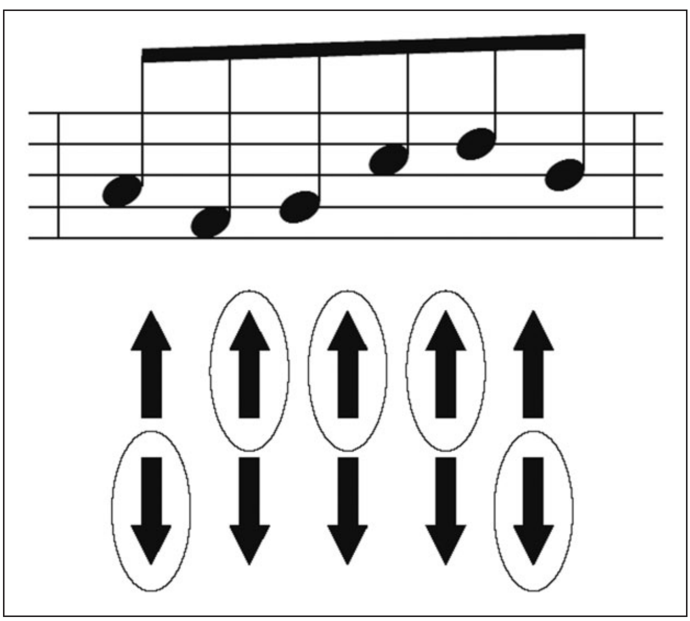

Figure 1. An example of tone-to-tone pitch transitions moving upward and downward and the corresponding (correct) responses as marked on the response sheet used in Experiment 1. (Only one ear stream is shown here for the sake of clarity, although two simultaneous streams were presented.)

participants were classified as musically trained. Twelve participants (11 right-handed) were lower-level or upper-level undergraduates in a university psychology department; these participants were classified as musically untrained. Eliminating the one left-handed individual (with 3 years of musical experience) from the analyses did not alter the pattern of results; therefore, this individual was retained for the analyses presented later. This sample size was relatively small; however, a priori power analyses indicated that as few as 12 individuals could represent an appropriate sample size to achieve 80% power at $\alpha = .05$. Further, this sample size was consistent with extant work assessing similar phenomena (e.g., Deutsch, 1985; Dowling, 1984).

Self-reported years of musical experience of musically trained participants ($M = 14.71$ years, $SD = 6.94$, and range = 9–26.5 years) was significantly larger than self-reported years of musical experience of musically untrained participants ($M = 4.20$ years, $SD = 3.88$, and range = 0–11 years; $t(16) = 4.15$, $p < .001$, Cohen's $d = 2.08$, large effect). Musical experience[2] included years of self-study, music lessons, and corporate musical experiences such as band, orchestra, or choir (cf. Hutchison, Hubbard, Hubbard, Brigante, & Rypma, 2015). Many of the musically untrained participants indicated that their experiences were very limited even for the years of experience reported, and that they did not consider themselves to be musicians. One individual in the musically untrained group did not divulge information regarding her musical experience.

All participants had self-reported normal hearing, with the exception of two piccolo players who self-reported mostly normal hearing with some hearing loss in the right ear within the extremely high end of the piccolo range. None of the stimuli in the experiment presented here were that highly pitched. Further, because these individuals' responses did not constitute performance outliers, they were retained in all analyses. In retrospect, one potential limitation of this study is that a clinical audiometer test was not used to compare participants' left and right ear hearing abilities to confirm that participants were free from auditory restrictions or biases.

Apparatus and materials

Auditory stimuli. Two different auditory streams were presented simultaneously on each trial; one stream was presented to the left ear, and the other stream was presented to the right ear. Twenty different auditory stimuli were created (each consisting of two separate streams), and each stream was used once as a left ear stream and once as a right ear stream (resulting in a total of 40 stimulus presentations). Consistent with Deutsch (1985), each auditory stream consisted of six consecutive tones (see Figure 2) in the key of F and in the range of F4 (349 Hz) to F5 (698 Hz); however, the frequency range in Experiment 1 was slightly larger than the frequency range used by Deutsch in order to accommodate contrary motion within stimuli (i.e., different directions of pitch motion in the left ear stream and in the right ear stream) at each transition. Tones were eighth notes at a tempo of 60 beats per minute, and thus 6-note-long streams were 3 seconds in duration. This rate of stimulus presentation was consistent with extant memory shadowing research (Norman, 1969) in which two words were spoken each second—a pace of presentation that allowed for stimuli in both auditory streams to be processed within working memory. Each trial was preceded by an F4 warning tone that lasted one beat, followed by a rest that lasted two beats. Cakewalk Sonar Studio 3.0 software was used to prepare MIDI stimuli, which were recorded onto a stereo audio track using an acoustic piano sound patch. The audio tracks were exported in MP3 format. Care was taken to ensure that no crosstalk between tracks was present. Thus, one stream was delivered exclusively to the right ear, and the other stream was delivered exclusively to the left ear.

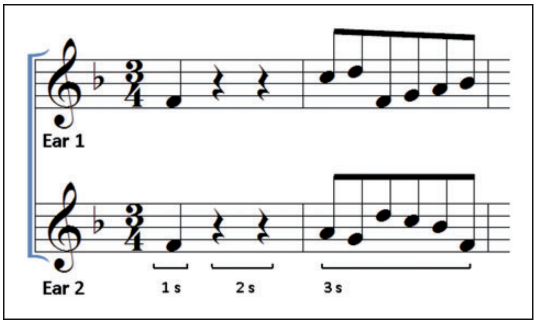

Figure 2. An example of the structure of a stimulus. The initial quarter note (F) served as the warning tone (same on all trials), then there was a pause of two beats, and then the six eighth notes of the stimulus.

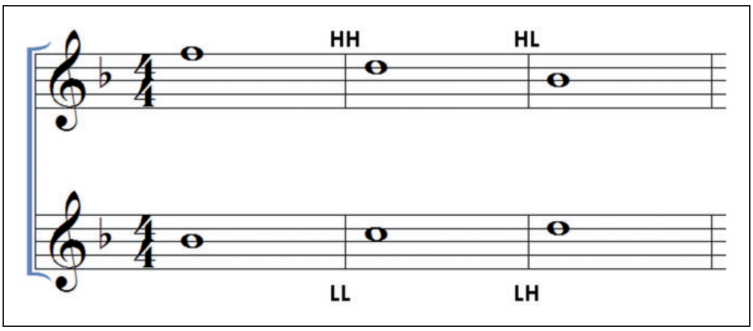

Figure 3. A simplified depiction of the four different pitch transitions used in the Experiment 1: LL (lower tone to lower tone), LH (lower tone to higher tone), HL (higher tone to lower tone), and HH (higher tone to higher tone).

To prevent judgment of a pitch transition in the unattended ear as being scored as a correct judgment of a pitch transition in the attended ear, the left ear stream and the right ear stream were generally in contrary motion (i.e., when the pitch transition in one ear moved up in pitch, the concurrent pitch transition in the other ear moved down in pitch). Due to experimental constraints, approximately 1% of pitch transitions occurred in similar motion; however, for both ear streams, all judgments involved pitches moving in either upward or downward motion. As shown in Figure 3, there were four types of pitch transitions between tones: (a) LL, a transition from a low tone to another low tone; (b) LH, a transition from a low tone to a high tone; (c) HL, a transition from a high tone to a low tone; and (d) HH, a transition from a high tone to another high tone. Tones were considered low or high based upon their frequency relative to the pitch presented simultaneously in the other ear rather than their actual frequency (cf. Deutsch, 1985; additionally, pilot testing indicated that relative pitch was more salient than absolute frequency).

Response materials. Participants were provided with a pencil and a packet of paper response sheets. The response sheets included a set of five arrows that pointed upward or downward (corresponding to pitch transitions; see Figure 1) for each of three practice trials and 40 experimental trials.

Presentation materials. Stimuli were presented on a Compaq Pentium IV Personal Computer operating a Microsoft Windows XP environment and using Microsoft PowerPoint as the stimulus presentation package. A sound level of approximately 57 dB (measured with a Radio Shack Digital Sound Level Meter, Cat. No. 33-2055) was used for all stimuli, and as the range of auditory frequencies was small, loudness was not adjusted to compensate for differences in auditory frequency. Stimuli were delivered over Koss UR-15C headphones, and a built-in pad encircled the speakers such that outside noises were dampened and comfort was maximized.

Procedure

The experimental trials were preceded by examples of auditory stimuli and then by three practice trials. On each trial, participants heard a single presentation of the auditory stimulus, after which they marked the five pitch transitions (between the six tones) heard in the attended ear by circling the appropriate upward or downward arrows on the response sheet. Participants heard the entire stimulus prior to responding; however, it is unlikely that this manipulation resulted in memory overload (cf. Tierney, Bergeson-Dana, & Pisoni, 2008). Presentation of ascending or descending transitions of high tones and low tones in the left ear stream and in the right ear stream was counterbalanced across participants. There was a 30-second silent interval between trials to allow any short-term memory trace to decay and to reduce potential interference between trials.

There were two blocks of experimental trials. In the first block, participants were instructed to (a) attend the tones in the left ear and ignore the tones in the right ear or (b) attend the tones in the right ear and ignore the tones in the left ear. In the second block, participants were instructed to (a) attend the tones in the ear they had ignored in the first block and (b) ignore the tones in the ear they had attended in the first block. There were 20 trials in each block for a total of 40 trials, with instruction order (i.e., attend to the left ear or the right ear first) counterbalanced across participants. A 3-minute break occurred between the first and second blocks. At the conclusion of the experimental trials, a brief musical experience questionnaire was administered to participants, and then participants were debriefed, thanked, and dismissed. The entire procedure took approximately 45 minutes per participant.

Results

A preliminary analysis examined whether accuracy rates were higher than chance (.50). Overall, accuracy for judgments of pitch transitions in the left ear ($M = .66$, $SD = 0.20$; $t(18) = 3.49$, $p < .003$, $d = 1.65$, large effect) and in the right ear ($M = .64$, $SD = 0.19$; $t(18) = 3.09$, $p = .006$, $d = 1.46$, large effect) were higher than chance. Accuracy for musically trained participants ($M = .81$, $SD = 0.16$; $t(6) = 5.19$, $p = .002$, $d = 4.24$, large effect) was higher than chance; however, accuracy for musically untrained participants ($M = .55$, $SD = 0.12$; $t(11) = 1.42$, $p = .184$, $d = .86$, large effect) did not differ from chance.

Data were then analyzed with a generalized linear model using maximum likelihood estimation of β (i.e., PROC GENMOD) in the SAS statistical programming language (SAS Institute, 2003a), with musical training (yes, no), pitch transition (LL, LH, HL, HH), and ear of presentation (left, right) predicting participant responses. Generalized estimating equations (SAS Institute, 2003b) allowed for the binary distribution of responses (i.e., correct, incorrect) and multiple responses per participant. An exchangeable covariance structure was utilized in this model.

As shown in Figure 4, musically trained participants were more accurate than were musically untrained participants ($\beta = -1.30$, $SEM = 0.36$, $p < .001$). Accuracy was not

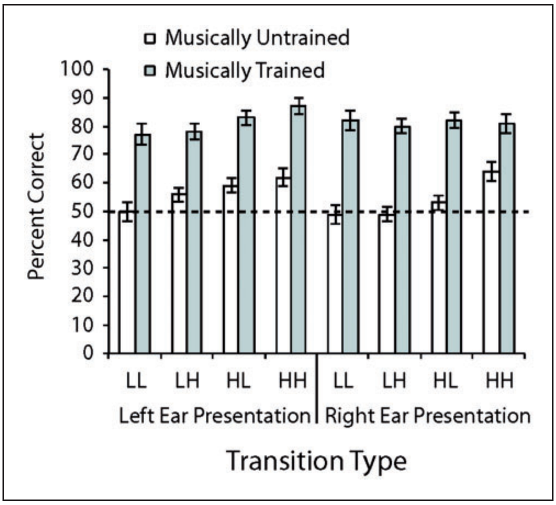

Figure 4. Percent of correct responses by ear of presentation and transition type in Experiment 1. The dashed line indicates chance, and error bars indicate standard error of the mean.

affected by ear of presentation ($\beta = 0.10$, $SEM = 0.12$, $p = .380$). This was also true when separating the models by musical experience; neither musically trained participants ($\beta = -0.02$, $SEM = 0.14$, $p = .894$) nor musically untrained participants ($\beta = 0.15$, $SEM = 0.15$, $p = .324$) exhibited an ear advantage. Additionally, there was a main effect of pitch transition across all participants such that judgments of HH pitch transitions were more accurate than judgments of LL pitch transitions ($\beta = 0.49$, $SEM = 0.24$, $p = .041$). In fact, a planned contrast indicated that HH pitch transitions were judged more accurately than all three other types of transitions ($\chi^2(1) = 4.85$, $p = .028$). However, when separating the models by musical training, only musically untrained participants exhibited this processing facilitation for judgments involving higher pitches (musically untrained: $\chi^2(1) = 4.62$, $p = .032$; musically trained: $\chi^2(1) = 0.56$, $p = .456$).

Finally, the laterality index (Repp, 1977; see also Seghier, 2008) was calculated for all participants as (left ear accuracy − right ear accuracy) / (left ear accuracy + right ear accuracy). As implemented here, a laterality index value that differs significantly from 0 indicates an advantage in processing of one ear over the other. Neither musically untrained ($M = 0.03$, $SEM = 0.04$; $t(11) = 0.75$, $p = .471$) nor musically trained ($M = -0.002$, $SEM = 0.02$; $t(6) = -0.13$, $p = .904$) participants' laterality index values differed from 0. Furthermore, the two groups did not differ from one another, $t(15.15) = 0.73$, $p = .478$, $d = 0.31$, small effect).

Discussion

Musically trained participants were successful at tracking pitch transitions for a specified ear stream, but musically untrained participants were not able to track pitch transitions for a specified ear stream. This finding is consistent with other studies in which musicians have demonstrated greater accuracy than nonmusicians in judgments of musical stimuli (e.g., Crawley, Acker-Mills, Pastore, & Weil, 2002). Musically untrained participants seemed to be more sensitive to pitch height than to location, as they were better able to track transitions between high tones even though they did not appear capable of tracking transitions within a specific ear. This is consistent with Deutsch's (1985) finding that musicians notated higher pitches more accurately than they notated lower pitches. Neither musically trained participants nor musically untrained participants exhibited an ear advantage for high tones or for low tones, and thus, the finding of a right-ear advantage for high tones and a left-ear advantage for low tones was not replicated in musically trained participants nor found in musically untrained participants.

The lack of ear advantages in musically inexperienced participants might reflect a floor effect due to the difficulty of the task for untrained participants rather than a lack of ear advantages for pitch per se. However, as evidenced by the result that musically untrained participants exhibited a processing facilitation for judgments involving higher pitches, the task was well understood and was not too difficult for them under certain conditions (ostensibly those most optimal for stimulus processing). One possible explanation for the lack of ear advantages in general in Experiment 1 is that ear advantages might require a greater level of musical training and experience than that possessed by the musically trained participants (upper level undergraduates in a music program). Even so, the task was not presumably more difficult than normal processing of multipart music in the everyday lives of participants. A second possible explanation involves the methodology: The original notation task (Deutsch, 1985) might have induced greater focus on chroma or pitch height than on musical contour, whereas the pitch transition judgment task in Experiment 1 might have induced greater focus on musical contour than on chroma or pitch height. Regardless, results of Experiment 1 suggest that neither musically trained nor musically untrained participants experienced lateralization that conferred a specific ear advantage. Based on this observation, a performer/audience paradox is not likely to occur.

Experiment 2

In Experiment 1, musically untrained participants judged transitions between high tones more accurately than other types of transitions. It is likely that there was no effect of pitch height for musically trained participants because these participants were able to successfully attend to the left or the right ear stream as instructed. The higher accuracy of pitch transition judgments in the HH condition for musically untrained participants suggests that keeping high tones of a given stream in the same ear might aid in tracking the musical contour of that stream. Greater accuracy with high tones is consistent with observations that sound qualities that tend to capture attention (e.g., movement, changes in dynamics, etc.) are often within a higher register and that within multipart music, the melody is often within a higher voice (e.g., Farnsworth, 1938; Lee, Skoe, Kraus, & Ashley, 2009; Marie & Trainor, 2013; Platt & Racine, 1990). To disentangle ear advantage effects from effects of relative pitch height, Experiment 2 evaluated whether participants in a selective attention task can accurately attend to a high-pitch stream or a low-pitch stream if that stream shifts between ears. If a right-ear or a left-ear advantage exists for high or low tones, respectively, we would expect pitch transition judgments to be facilitated for higher tones when the stream stays in the right ear and to be facilitated for lower tones when the stream stays in the left ear.

Method

Participants

Twelve participants (all right-handed) from a university psychology department, unselected for musical experience and who had not participated in Experiment 1, were recruited to participate and received partial course credit for their participation. This sample size was relatively small; however, a priori power analyses indicated that as few as 12 individuals could represent an appropriate sample size to achieve 80% power at $\alpha = .05$. Further, this sample size was consistent with extant work assessing similar phenomena (e.g., Deutsch, 1985; Dowling, 1984).

Given that musically experienced participants in Experiment 2 had relatively little formal training in music (and that more musical experience does not necessarily imply more formal training), a nomenclature of *experienced* and *inexperienced* rather than *trained* and *untrained* was used to distinguish the experienced but relatively untrained participants in Experiment 2 from the more highly trained participants in Experiment 1. Participants with 3 or more years of musical experience (practicing instruments, singing, taking lessons, and group participation in instrumental or vocal activities) were classified as musically experienced ($n = 7$), and participants with less than 3 years of musical experience were classified as musically inexperienced ($n = 5$; cf. Hutchison et al., 2015). The 3-year criterion provided a differentiation between the participants in the present study in terms of both quality and quantity of musical experience. All participants had self-reported normal hearing.

Apparatus and materials

The apparatus and materials were the same as in Experiment 1, with the following exception: Given that participants were instructed to attend to pitch height, rather than to ear of presentation, it was necessary to add a response option that a tone repeated in pitch to the response sheets used in Experiment 2, as 13% of transitions included a repeated pitch. Other than the 1% of transitions that were in similar motion (as mentioned in Experiment 1), all remaining transitions were in contrary motion. This option was in the form of a horizontal dash located between each upward arrow and downward arrow on the response sheet; these horizontal dashes were not needed in Experiment 1 because pitches presented to a given ear in Experiment 1 always moved upward or downward and thus never stayed the same during a transition.

Procedure

The procedure of Experiment 2 was the same as that of Experiment 1, with the following exception: Rather than attending to tones presented to the left ear in one block of trials and to tones presented to the right ear in another block of trials, participants attended to high tones in one block of trials and to low tones in another block of trials.

Results

A preliminary analysis examined whether accuracy rates were higher than chance (.33). Overall, accuracy for judgments of pitch transitions in the high stream ($M = .53$, $SD = 0.13$; $t(11) = 5.26$, $p = .0003$, $d = 3.17$, large effect) was higher than chance, and accuracy for judgments of pitch transitions in the low stream ($M = .39$, $SD = 0.10$; $t(11) = 2.06$, $p = .064$, $d = 1.24$, large effect) was marginally higher than chance. Accuracy rates for musically experienced participants ($M = .46$, $SD = 0.06$; $t(6) = 5.78$, $p = .001$, $d = 4.72$, large effect) and musically inexperienced participants ($M = .46$, $SD = 0.04$; $t(4) = 7.28$, $p < .002$, $d = 7.28$, large effect) were higher than chance.

Examination of generalized estimating equations was conducted using a model incorporating musical experience (yes, no), pitch stream (high, low), and ear transition (right to right [RtRt], right to left [RtLt], left to right [LtRt], left to left [LtLt]) as predictors of accuracy. There was no significant main effect of musical experience ($\beta = 0.01$, $SEM = 0.11$, $p = .901$). As shown in Figure 5, judgment accuracy was greater for the high-pitch stream than for the low-pitch stream ($\beta = 0.58$, $SEM = 0.24$, $p = .016$).

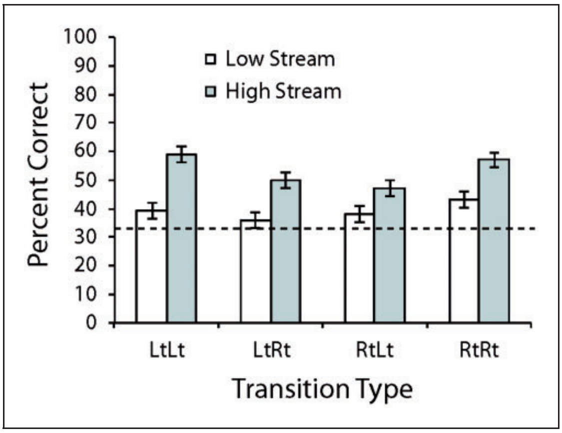

Figure 5. Percent of correct responses for low and high streams by transition type in Experiment 2. The dashed line indicates chance, and error bars indicate standard error of the mean.

Accuracy was significantly less on RtLt transitions than on RtRt transitions ($\beta = -0.32$, $SEM = 0.07$, $p < .0001$). Accuracy was marginally less on LtRt transitions than on RtRt transitions ($\beta = -0.32$, $SEM = 0.18$, $p < .080$). LtLt transitions did not differ in accuracy from RtRt transitions ($\beta = -0.05$, $SEM = 0.08$, $p = .548$). A planned contrast between same-ear transitions (LtLt, RtRt) and cross-ear transitions (RtLt, LtRt) indicated that participants were significantly more accurate when the auditory stream remained in the same ear ($\chi^2(1) = 5.55$, $p = .018$).

A model incorporating an interaction between pitch stream and ear transition required the estimation of more parameters than would be ideal. In fact, planned contrasts between high/right with high/left and low/left with low/right stimulus presentation were not estimable. Therefore, least squared mean (*LSM*) difference estimates were used to contrast high pitch/RtRt ($LSM = 0.30$, $SEM = 0.23$) with high pitch/LtLt stimulus presentation ($LSM = 0.37$, $SEM = 0.15$; *difference estimate* [*de*] $= -0.07$, $SEM = 0.19$, $p = .716$), and low pitch/LtLt ($LSM = -0.43$, $SEM = 0.18$) with low pitch/RtRt stimulus presentation ($LSM = -0.27$, $SEM = 0.20$, $de = -0.17$, $SEM = 0.17$, $p = .339$). These contrasts resulted in no significant differences (all *p*s $> .05$). Thus, the results did not lend evidence to support that accuracy was greater for high tones in the right ear or for low tones in the left ear.

As in Experiment 1, a linear mixed model (SAS PROC MIXED) was employed as an alternative method of analyzing the data after converting responses from binary (correct, incorrect) to proportion of correct responses. This method was employed to evaluate interactions, although it generally requires a greater sample size than the generalized linear model in order to achieve adequate power.

The linear mixed model revealed two significant interaction effects. An interaction between pitch stream and musical experience revealed that whereas musically inexperienced participants achieved similar accuracy for high ($M = 0.46$, $SD = 0.50$) and low ($M = 0.47$, $SD = 0.50$) auditory streams, $t(10) = -0.05$, $p = .957$, $d = -0.02$, no effect, musically experienced participants were more accurate for high ($M = 0.58$, $SD = 0.49$) than for low ($M = 0.34$, $SD = 0.47$) auditory streams, $t(10) = 4.03$, $p = .002$, $d = 0.50$, medium effect, $F(1, 10) = 6.98$, $p = .025$. Further, an interaction between ear transition and musical experience revealed that musically experienced participants were more accurate for LtRt transitions ($M = 0.50$, $SD = 0.50$) than for RtLt transitions ($M = 0.39$, $SD = 0.49$), $t(10) = 4.94$, $p < .001$, $d = 0.22$, small effect, whereas musically inexperienced participants were less accurate for LtRt transitions ($M = 0.32$, $SD = 0.47$) than for RtLt transitions ($M = 0.48$, $SD = 0.50$), $t(10) = -5.70$, $p < .001$, $d = -0.33$, small effect, $F(3, 10) = 31.98$, $p < .0001$. The interaction between ear transition and pitch stream was not significant, $F(3, 10) = 0.72$, $p = .563$, nor was there a three-way interaction of ear transition, pitch stream, and musical experience, $F(3, 10) = 1.07$, $p = .404$.

Discussion

Consistent with the ability of musically trained participants to judge pitch transitions in both the left ear stream and in the right ear stream in Experiment 1, musically experienced participants were able to judge pitch transitions in the high stream and in the low stream in Experiment 2. Additionally, musically inexperienced participants were able to judge pitch transitions in the high stream and in the low stream in Experiment 2. A question generated from these observations is why musically inexperienced or untrained participants were able to judge pitch transitions within a high or a low stream that crossed ears (Experiment 2), but yet they were not able to judge pitch transitions within a single ear stream containing both high and low tones (Experiment 1). One possibility is that relative pitch height (attended in Experiment 2) is a more salient cue or dimension for auditory stimuli than is location (e.g., left or right; attended in Experiment 1). Such a conclusion would be consistent with the octave illusion (Deutsch, 1999), which demonstrates perceptual grouping of musical tones on the basis of auditory frequency rather than on the basis of ear of presentation.

Overall, accuracy was greatest for pitch transitions in the high stream and for pitch transitions in the same ear. The overall better performance for high tones regardless of ear of presentation, and the lack of effects when pitch transitions between high tones and low tones crossed ears, is not consistent with ear advantages for highly trained musicians (e.g., Deutsch, 1985). However, the small interaction effects between musical experience and pitch stream, and between musical experience and ear transition, suggest that there might be instances in which relative tonal height and ear of presentation matter, and that these factors might differentially affect those with more or less musical experience.

It is possible that any potential ear advantage was overshadowed by the effects of selective attention. In Experiment 2, participants attended to only a portion of the total stimulus (i.e., the high stream or the low stream), and this attentional strategy would have been different from the strategy used previously (i.e., Deutsch, 1985), in which participants were instructed to attend to the entire stimulus. The higher accuracy for pitch transitions in the high stream is consistent with (a) better accuracy in the HH condition in Experiment 1 and with (b) the typical placement of melody in the high voice. Higher accuracy for pitch transitions in the high stream is inconsistent with an alternative hypothesis based on masking; the typical upward spread of masking would predict that lower tones would mask higher tones (cf. Zwicker & Scharf, 1965). The decrease in accuracy when pitch transitions occurred between ears, relative to when pitch transitions occurred within the same ear, likely reflects the shift of attention between ears.

General Discussion

In the present experiments, we sought to determine whether processing advantages occurred in musically untrained or inexperienced music listeners for right/high and left/low musical presentations. We further investigated whether any such processing advantage might be affected by attention. In Experiment 1, instructions involving ear of presentation in a dichotic listening task resulted in musically trained participants exhibiting greater accuracy in judgments of pitch transitions between tones than musically untrained participants. Musically untrained participants were most accurate in judgments of pitch transitions between two relatively high tones. In contrast to previous work (Deutsch, 1985), advantages for high tones presented to the right ear and for low tones presented to the left ear were not observed. Pitch height was not related to a relative ear advantage in this task.

In Experiment 2, we sought to further examine the issue of pitch height by instructing participants to attend to either the relatively higher or relatively lower pitched auditory stream in a dichotic listening task, regardless of ear of presentation. Accuracy was greater for pitch transitions in the high stream and was greater when a stream was maintained within a single ear; however, there was no consistent ear advantage or main effect of musical experience. Thus, it might be that attentional strategy is a stronger predictor of musical processing than potential ear advantages for relative pitch height. Indeed, it is believed that top-down attentional control mechanisms act to shape perception in both the auditory and visual domains (e.g., Gregoriou et al., 2009; Tervaniemi et al., 2009; see also Engel, Fries, & Singer, 2001; Miller & Cohen, 2001). However, the extent to which attention and prior knowledge interact, and the degree to which these factors might influence perception, still require further investigation.

The criterion for separating musically experienced participants from musically inexperienced participants was different in Experiments 1 and 2, and the different criteria might initially appear to make comparisons across experiments challenging (e.g., the mean experience of musically untrained participants in Experiment 1 was 4.2 years, which would have qualified many of those musically inexperienced participants as musically experienced participants in Experiment 2). However, the critical comparisons were within each experiment rather than across experiments, and so the differences in participants between Experiment 1 and Experiment 2 are not necessarily problematic. Indeed, such differences could suggest generalizability of the present findings. Even so, results might reflect the different participant populations (e.g., a main effect of musical experience in Experiment 1 but a lack of such an effect in Experiment 2 is consistent with the notion that formal musical training is required in order to exhibit the effects Deutsch observed). Importantly, a primary goal of the current experiments was to consider the possibility of a performer/audience paradox. It was therefore necessary to assess whether ear advantages for pitch could be found in individuals who were *not* highly trained musicians. Thus, the use of different participant populations is not a critical issue, as each experiment contained individuals who were not musically trained. The results of the present experiments do not support existence of a consistent ear advantage in musically inexperienced listeners, and thus do not lend evidence to support a possible performer/audience paradox.

Interestingly, in Experiment 1, higher tones were associated with facilitated performance in untrained participants, whereas in Experiment 2, higher tones were associated with facilitated performance in experienced participants. Given the different participant groups in the two experiments, there is likely a range of musical training and experience that confers a facilitation of performance when pitches in the relatively higher stream are the focus of attention (similar to a traditional melody carried in a relatively high voice); however, this facilitation might not be similarly evidenced at very low or very high levels of training or experience. Further, any facilitation that might result from musical experience cannot be clearly related to lateralization effects.

Although the results from Experiments 1 and 2 are not consistent with previous behavioral research (e.g., Bever & Chiarello, 1974; Deutsch, 1985), these results are consistent with recent neuroimaging studies. Schirmer et al. (2012) conducted a meta-analysis of functional neuroimaging studies using auditory stimuli. They found both left and right temporal cortices to be active when processing music and concluded that the driving factor in hemispheric specialization was the listener's history and experience with the auditory landscape. Similarly, using magnetoencephalography, Shaw, Hämäläinen, and Gutschalk (2013) demonstrated that a rightward bias in neural activity could be offset by cortical activity in the left hemisphere, to the extent that different attentional strategies result in different patterns of cortical activity. In conjunction with our behavioral data, the neuroimaging data suggest that attentional strategy can overcome potential effects of cerebral asymmetry regarding pitch height or chroma, affecting music perception. Such a conclusion is consistent with findings of numerous other researchers indicating that attention influences the physiology involved in perception (e.g., Bouvier & Engel, 2011; Hugdahl et al., 2000; Picton & Hillyard, 1974).

Our results suggest three additional conclusions. First, musically trained participants are more capable in selectively allocating their attention to specific aspects of musical stimuli than are musically untrained participants (Experiment 1). The lower level of performance for musically untrained participants is not likely due to a floor effect, as untrained participants were more successful with transitions that were maintained within the higher voice (i.e., HH transitions), and their variability was similar to that of the musically trained group (see Figure 4). Second, both musically experienced participants and musically inexperienced participants are more accurate for same ear presentation of elements of a given auditory stream (Experiment 2). Both the scale illusion (e.g., Deutsch, 1999) and findings from auditory streaming studies (e.g., Beauvois, 1998; Bregman, 1990) suggest that following a stream of tones across ears is possible and even probable. However, when a given auditory stream stays in the same ear, it is easier to follow. Given that natural objects do not discontinuously change position in space, such a strategy would presumably be adaptive for the tracking of auditory objects in the environment. Third, participants are better able to follow an auditory stream composed of high tones than an auditory stream composed of low tones (Experiment 2). This latter conclusion is consistent with findings that infants exhibit greater and earlier mismatch negativity when hearing changes in higher pitched musical stream (Marie & Trainor, 2013) and with findings that pitch height is the most salient cue in selective attention for rapidly presented tones (Woods, Alain, Diaz, Rhodes, & Ogawa, 2001). It is possible that relatively high pitch is a particularly salient cue that aids entrainment for music listeners, given that a primary mechanism of selective attention at the neural level is entrainment to stimuli (cf. Calderone, Lakatos, Butler, & Castellanos, 2014) and given the common practice of placing the melody in a higher register.

Multiple neural networks in both cerebral hemispheres are thought to be involved in processing music (Parsons, 2003), with some cortical areas exhibiting differences between musicians and nonmusicians (e.g., left dominance in superior temporal area for musicians and right dominance in superior temporal area for nonmusicians) and other cortical areas failing to exhibit such differences between musicians and nonmusicians (e.g., middle and inferior temporal areas). Listeners with musical experience might have relied on different processing systems for our tasks than did listeners without musical experience. Neuroimaging experiments using visual search tasks indicate that there are attentional templates regarding the location of an object of interest (or *where*) and the object of interest itself (or *what*), and that search is impacted by both familiarity and previous experience (see Peelen & Kastner, 2014). We addressed these issues of *where* and *what* within the auditory domain in Experiment 1 (left or right ear) and in Experiment 2 (high or low auditory stream), respectively. We found that experience impacted the *where* system more than the *what* system in our experiments and with our participants, such that musically experienced participants were successful in the ear location task under conditions in which less-experienced participants were not successful; however, both groups were successful in the high or low stream task. Future research should further explore how music processing is affected by experience, in terms of both auditory sound location and auditory stimulus attributes.[3] Specifically, it would be interesting to examine corporate (i.e., group-based) musical experience and its effect on lateralization, given that individual musicians are arranged in spatial formations when rehearsing or performing in groups. Such experience could potentially alter one's lateralization experience.

One concern regarding the present experiments might be whether the task is overly taxing upon working memory stores, as participants listened to the entire auditory sequence prior to providing their responses regarding pitch transitions. However, demands of our task were within the range of both musicians' and nonmusicians' auditory working memory capacity. Tierney et al. (2008) showed that musicians outperformed other groups (gymnasts, psychology students, and video gamers) on auditory sequence memory but not on visual sequence memory, but all groups achieved a minimum weighted span score of at least five items. Evidence suggests that when working memory overload does occur, it affects higher and lower performing individuals differentially (e.g., Jaeggi et al., 2007). If higher performing individuals were more often musically trained or experienced, or if working memory overload only occurred for individuals lacking musical training or experience (due to musicians' enhanced auditory sequence memory; cf. Tierney et al., 2008), results might be systematically affected. Such differences would serve to explain why those with musical training or experience process music differentially from those with less training or experience, but it would not diminish the impact of any observed differences, such as a performer/audience paradox. It is not immediately apparent how such an overload of working memory might influence lateralization; however, this could be a fruitful avenue for future research.

In summary, results of the current study suggest that the ear advantages for high tones and for low tones that were reported by extant work for trained musicians (e.g., Deutsch, 1985) might not exist in musically untrained or inexperienced participants. Alternatively, it is possible that such ear advantages might exist but are relatively fragile and can be influenced by attentional strategy. The experiments reported here suggest that an ear advantage does not exist when attention is selectively focused on a particular ear of presentation or on relative pitch relationships within a sound dyad (i.e., a stream created by focusing exclusively on either the higher or the lower pitches). Any potential ear advantages (and underlying cerebral asymmetries) for processing of high tones or low tones do not appear to strongly influence the listening of musically untrained or inexperienced individuals. However, there is a general advantage for the higher pitched stream, possibly due to entrainment to the auditory stimulus via selective attention. Given the lack of present evidence supporting ear lateralization in musically untrained and inexperienced listeners, a performer/audience paradox based on the traditional spatial arrangement of performers and audience does not seem likely in the performance and perception of music.

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Notes

1. Even if the pitch-based ear advantages reported in Deutsch (1985) occur in nonmusicians, it is not clear that this would necessarily lead to a performer/audience paradox. In most music venues, sounds reflect from surfaces near the performers and audience, and so each ear receives a mixture of sounds from different sources. There would be few, if any, locations in a given venue in which high and low instrumental sounds would be as precisely localized as in a dichotic listening task. Such a view suggests that it might not be useful to assess ear advantages; however, Hugdahl (2003) concluded in a review of the literature that dichotic listening tasks are useful in assessing auditory laterality.
2. It is important to note that the definition of musicianship varies widely throughout the literature. For example, Musacchia, Strait, and Kraus (2008) used very strict criteria for musicianship in their electroencephalographic study in which they related neurophysiological responses to musical experience. They defined musicians as individuals who began their musical experience prior to the age of 5 years, who had 10 or more years of experience, and who engaged in regular and substantial hours of practice. Deutsch (1985) also required 10 or more years of training but did not include the additional stipulations. Dowling (1984) defined musicians as individuals with 2 or more years of experience (lessons on an instrument or voice). Hutchison et al. (2015) employed a 3-year experience criterion, including self-study, lessons, and group-based musical experiences.
3. Along these lines, experiments conducted within a concert hall setting with controlled reverberation times for high and low frequencies (e.g., Eugene McDermott concert hall in the Meyerson Symphony Center in Dallas, Texas; see Beranek, 1992) could be particularly informative in extending our understanding of the auditory milieu for both musically trained and inexperienced listeners, as well as in examining how different structural qualities might compensate for any performer/audience paradox. All performance spaces are not created equal (cf. Hidaka & Beranek, 2000), and the additional understanding of how both trained and untrained minds process incoming musical stimuli within specific environments would further our understanding of ecologically valid audience or performer perceptual dynamics and thus be beneficial in the advancement of psychoacoustical engineering.

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