Magnetoencephalography evidence for different brain subregions serving two musical cultures

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Individuals who have been exposed to two different musical cultures (bimusicals) can be differentiated from those exposed to only one musical culture (monomusicals). Just as bilingual speakers handle the distinct language-syntactic rules of each of two languages, bimusical listeners handle two distinct musical-syntactic rules (e.g., tonal schemas) in each musical culture. This study sought to determine specific brain activities that contribute to differentiating two culture-specific tonal structures. We recorded magnetoencephalogram (MEG) responses of bimusical Japanese nonmusicians and amateur musicians as they monitored unfamiliar Western melodies and unfamiliar, but traditional, Japanese melodies, both of which contained tonal deviants (out-of-key tones). Previous studies with Western monomusicals have shown that tonal deviants elicit an early right anterior negativity (mERAN) originating in the inferior frontal cortex. In the present study, tonal deviants in both Western and Japanese melodies elicited mERANs with characteristics fitted by dipoles around the inferior frontal gyrus in the right hemisphere and the premotor cortex in the left hemisphere. Comparisons of the nature of mERAN activity to Western and Japanese melodies showed differences in the dipoles' locations but not in their peak latency or dipole strength. These results suggest that the differentiation between a tonal structure of one culture and that of another culture correlates with localization differences in brain subregions around the inferior frontal cortex and the premotor cortex.

Keywords: music; biculturalism; tonal deviants; brain activity; MEG

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1. Introduction

Music may be universal, however its features are diverse across cultures. One feature that differs across cultures is the “musical scale.” Musical scale is generally a well-known term, but in psychological terms we prefer referring to its neural correlate in the brain as a “tonal schema.” One particular musical schema, the tonal schema is learned via exposure to music of ones’ culture (e.g., Krumhansl & Cuddy, 2010). For example, a listener exposed to music generated from a Western diatonic scale acquires a different tonal schema from another listener exposed to music from a traditional Indian scale; and the two listeners perceive different tonal organizations when hearing a piece of Western diatonic music or traditional Indian music. Thus, as with language, tonality perception is a culture-specific phenomenon.

Just as there are individuals raised in bilingual environments can follow the speech of both languages, individuals who mature in bimusical cultures (i.e., a culture where two distinct music styles are prevalent) can also comprehend the nuances of music from two different cultures (e.g., Hood, 1960; Nettl, 2005; Randel, 2003). A bimusical culture allows listeners to acquire two distinct tonal schemas, respectively; and, as a result, bimusical listeners perceive the tonal musical structure of two different cultures using the distinct tonal schemas for each (e.g., Abe & Hoshino, 1990; Ogawa, Kimura, & Mito, 1995/1996; Wong, Roy, & Margulis, 2009). This is as if bilinguals comprehend the language-syntactic structure of the first language and that of the second language by using grammatical rules for each language. Behaviorally, monomusicals can also distinguish between two musical systems (i.e., native music and non-native music). However, they rely upon a distinctly different mechanism than bimusical listeners. That is, monomusicals rely solely on an overall impression of “foreignness”, i.e., a lack of familiarity, for their judgments whereas bimusicals are capable of actually differentiating the two kinds of culture-specific tonal structure on the basis of their respective tonal schemas (e.g., Hood, 1960; Nettl, 2005). In terms of this unique cognitive ability of bimusical listeners, it is possible that they have acquired a specific neural activity contributing to the differentiation of two culture-specific tonal structures. Indeed, this possibility is suggested by evidence in Wong, Chan, Roy, and Margulis (2011), which showed that bimusical brains have qualitatively different activation profiles from monomusical brains. However, little is known about the bimusicals’ neural activity involved in the tonal differentiation between two musical cultures.

A large number of studies have reported neural activity that provides a diagnostic of sensitivity to the processing of tonal structure. For instance, electroencephalography (EEG) studies have shown that a particular event-related potential (ERP) component is elicted when Western listeners hear an out-of-key tone (i.e., a tonal deviant) within a well established Western tonal context (e.g., Braticco, Tervaniemi, Näätänen, & Peretz, 2006; Garza Villarreal, Brattico, Leino, Østergaard, & Vuust, 2011; Koelsch, Gunter, Friederici, & Schröger, 2000; Koelsch & Jentschke, 2010; Koelsch, Jentschke, Sammler, & Mietchen, 2007; Loui, Grent-‘t-Joung, Torpey, & Woldorff, 2005; Loui, Wu, Wessel, & Knight, 2009; Miranda & Ullman, 2007; Peretz, Brattico, Järvenpää, & Tervaniemi, 2009). The ERP component has negative polarity, maximal amplitude values over frontal leads (with right-hemispheric predominance), a peak latency of 125-150 ms following a tonal deviant given by a single tone within a tone sequence (e.g., Koelsch & Jentschke, 2010; Paller, McCarthy, & Wood, 1992; Verleger, 1990) and 180-200 ms to a tonal deviant created by a chord within a chord sequence (e.g., Koelsch, et al., 2000; Loui et al., 2005). Interpretation of the ERP component is controversial (e.g., Garza Villarreal et al., 2011; Koelsch, 2009). One line of studies has claimed the ERP is a type of MMNs (e.g., Brattico et al., 2006; Näätänen, Paavilainen, Rinne, & Alho, 2007). This claim relies on evidence that characteristics described above for an observed ERP resemble those of mismatch negativity (MMN), which is elicited by any violation of an expectancy established by a coherent context. Another line of research has disputes this interpretation, instead referring to this ERP as “ERAN” (e.g., Koelsch et al., 2000; Koelsch, 2009). The label of “ERAN” for this ERP is designed to emphasize two ideas: One idea is that, unlike MMNs which are elicited by acoustic property deviants occurring in the oddball paradigm, an ERP termed ERAN reflects processing based on a music syntactic-knowledge; the other idea is that an ERP termed ERAN is a musical equivalent of the ELAN (early-left-anterior-negativity) effect, which reflects early language syntactic processing. Conceivably, the difference between these two positions, at least implicitly, may depend upon one's definition of MMN: the former extends the concept of MMN to include expectations based on long-term representations such as those involved in a linguistic grammar system, whereas the latter restricts the concept of MMN to expectations based on short-term representations such as those established on-line in the traditional oddball paradigm. Resolving this disagreement is outside the realm of the present study. However, it is pertinent to this study that these two lines of research both show that the ERP for tonal deviations reflects high-order processing based on a tonal schema. In this paper, independent of the above controversy, we refer to this ERP as “early-right-anterior-negativity (ERAN)” based upon its temporal and localization properties in the brain wave.

In addition to EEG studies, fMRI studies have shown that the activation of the inferior frontal cortex is associated with tonal processing (e.g., Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005; Koelsch, Gunter, Cramon, von Zysset, Lohmann, & Friederici, 2002; Levitin & Menon, 2003; Minati, Rosazza, D’lncerti, Pietrocini, Scaiolu, Loveday, & Bruzzone, 2008; Sammler, Koelsch, & Frederici, 2011; Seung, Kyong, Woo, Lee, & Lee, 2005; Tillman, Janata, & Bharucha, 2003; Wehrum, Degé, Ott, Walter, Sippekohl, Kagerer, Schwarzer, Vaitl, & Stark, 2011). For example, Koelsch et al. (2005) obtained fMRI data from three groups of listeners (10-year-old children, adult non-musicians, adult musicians) who judged musical sequences ending with either a tonally regular chord or an irregular chord. All listeners showed that activity elicited by the tonally deviant chord appeared in the same brain areas. These areas included the inferior frontolateral cortex and several areas in the right hemisphere, such as the ventral premotor cortex and the superior temporal gyrus.

Maess, Koelsch, Gunter, and Friderici (2001) indicated that the ERAN activity is closely related to activation of the inferior frontal cortex. Their magnetoencephalography (MEG) study attempted to identify the neural substrate responsible for the ERAN activity using a source analysis with equivalent current dipole modeling. The results revealed that tonal deviant chords in Western music elicited a magnetic ERAN (mERAN) originating in the inferior frontolateral cortex (specifically, the inferior portion of the pars opercularis). This finding suggests that mERAN results largely from neural sources located in the inferior frontal cortex.

The present MEG study focuses upon the magnetic ERAN activity and the activation of inferior frontal cortex in order to determine specific brain activities that contribute to differentiating the two culture-specific tonal structures in bimusical brains. Three hypotheses are posed regarding the mechanism for this differentiation. The first hypothesis, *the temporal hypothesis,* maintains that differences in the peak latency of neural activity contribute to the tonal differentiation of two musical cultures. Previous studies (e.g., Koelsch & Jentschke, 2010; Paller et al., 1992; Verleger, 1990) indicated that the ERAN has a peak latency of 125-150 ms following an out-of-key tone in a tone sequence. From this result, we predict that, while both peaks are within the time window of 125-150 ms, the peak latency of the mERAN for music of one culture (M1) will differ from the mERAN for music of another culture (M2). A second hypothesis, *the spatial locus hypothesis,* holds that differences in the spatial location of brain activation are responsible for the differentiation of two culture-specific tonal structures. This hypothesis predicts that locations of dipoles, estimated by source analyses of the mERAN, differ between M1 and M2. This extends to occupation by M1 and M2 of respectively different subregions within the specific cortical region, assuming that mERAN dipoles of the two types of music are located in the inferior frontal cortex. The third hypothesis, *the activation level hypothesis*, maintains that different levels of brain activation contribute to the differentiation of two culture-specific tonal structures. This hypothesis predicts that the strength of the dipoles will differ between M1 and M2.

The purpose of the present study was to identify particular brain activities in bimusicals that can shed light on differentiating tonal properties between the two culture-specific tonal structures. Specifically, we sought to determine which of the above three hypotheses, temporal, spatial, or activation level, provides the best description for differentiating the brain activities related to tonality. Our strategy for identifying these brain responses involved measuring bimusical listeners' MEG responses to music of two different cultures using tonal deviant listening task. In the task, the melodies participants listened to could contain an ending either with a tonally deviant note or not. Focusing on ERAN activity in response to tonal deviation tones (out-of-key notes), we attempted to identify which of three properties of ERAN activity --- its peak latency, source location, or source strength -- clearly differed when bimusical participants listened to music of one or the other culture. If such culture-specific properties of ERAN activity are identifiable, then it is possible to infer that the property of ERAN contribute to the differentiation between the two culture-specific tonal structures.

Participants of this study were born and bred Japanese. Present-day Japanese are native listeners of Western tonal music. However, they also have many oppotunities for exposure to a purely non-Westernized style of music, i.e., traditional Japanese music such as Minyo (Japanese folk music), Warabeuta (Japanese children songs), Hougaku (traditional Japanese music for koto, shamisen, and shakuhachi), Gagaku (ancient court music in Japan), and so on (e.g., Arimichi & Tsugami, 2007; Izumi, 1995). As a result of exposure to both Western music and the traditional Japanese music, present-day Japanese listeners typically become bimusical listeners (e.g., Abe & Hoshino, 1990; Koizumi, 1984; Ogawa et al., 1995/1996).

The musical scales used in traditional Japanese music are different from the Western diatonic scale. The most notable difference between traditional Japanese scales and Western diatonic scales is the number of scale tones. Traditional Japanese scales consist of five-scale tones (i.e., pentatonic scales) whereas Western diatonic scales consist of seven-scale tones. A more important difference, however, concerns the psychological hierarchy of scale tones. In traditional Japanese scales, the most important tone "kaku-on (i.e., a tonal center in general term; a tonic or a keynote in Western music term)" is followed by the tone that forms the interval of a perfect fourth above a kaku-on (e.g., Koizumi, 2009). That is, borrowing from the concept of Western music "the movable doh solmization system", doh (i.e., a tone corresponding to a tonal center) and fa play dominant roles in the traditional Japanese scale system. By contrast, in the Western diatonic scale system the most significant tone that follows a doh is sol; and sol forms the interval of a perfect fifth above a doh (e.g., Krumhansl, 1990). This difference in hierarchical tonal ordering is a critical differentiating property that separates the tonal hierarchy of Western tonal schema from that of traditional Japanese tonal schema (e.g., Hoshino, 1985). It means that listeners will perceive the pentatonic scales used in the traditional Japanese music as fundamentally different from the scales of Western music.

The melodies created for this study were designed to allow the attribution of any difference in observed brain activity between Western and Japanese music to the differences of perceived tonal structures. Many studies have demonstrated that the scale generating a melody principally governs the perception of tonal structure, which is indexed by sensitivity to tonal deviants (e.g., Matsunaga & Abe, 2005, 2012). In this study, we decided to create two groups of melodies that differed with respect to scales. One group of melodies conformed to the Western diatonic scale (i.e., doh-re-mi-fa-sol-la-ti in the notation of the movable doh solomization; e.g., the scale is notated as C-D-E-F-G-A-B when a doh is C) and the other conformed to the traditional Japanese Ritsu scale (i.e., doh-re-fa-sol-la). All other relevant musical features such as melodic contour, pattern of tone durations, melody length, timbre and so forth were held constant between the two groups.

It should be noted that all the five-scale tones of the Ritsu-scale are present in the Western diatonic scale. This means it is possible to have cases in which the doh-re-fa-sol-la scale appears as in Western music. In spite of this, as mentioned above, the difference in tonal hierarchical ordering allows us to assume that the Ritsu scale is psychologically different from the doh-re-fa-sol-la scale used in Western music (e.g., Koizumi, 2009). Accordingly, in this paper we refer to the doh-re-fa-sol-la scale using the appropriate Japanese term for this scale i.e., “Ritsu scale.” Nevertheless, this assumption has to be directly examined for us to consider its valid. Therefore, we tested this assumption in a pilot experiment conducted prior to the main MEG experiment (cf. below).

Moreover, it should be noted that the prevalence of Western tonal music in contemporary Japanese culture is quite broad; therefore, the Western tonal schema is arguably more strongly internalized than the traditional Japanese tonal schema in Japanese people (Abe & Hoshino, 1990). This factor raised sufficient concern that the degree of “a sense of tonality” (e.g., Boltz, 1989; Krumhansl, 1990) might be greater for Western than for Japanese music. Accordingly, even if the dipole strength of the mERAN differs between the two cultures, it remains necessary to take into account the possibility that such a disparity could merely reflect a quantitative difference in the degree of a sense of tonality rather than a qualitative difference in the tonal schemas. In this study, based on the results of pilot experiments (cf. below), we decided to select Western stimulus melodies and Japanese stimulus melodies that are comparable in their degree of “a sense of tonality.”

In order to verify that Japanese participants were true bimusicals of “Western music and traditional Japanese music”, we conducted the pilot study. In the pilot study, each of 24 Japanese participants heard 31 Western melodies and 31 Japanese melodies (see in-key version of each culture in Fig. 1). Japanese melodies were created from existing traditional Japanese music samples. For each sample, the first 23 tones were excerpted and modified to form a monophonic, isochronous melody. Each Japanese melody consisted of [doh, re, fa, sol, la]. On the other hand, the 31 Western music samples were designed to have one-to-one correspondence with the 31 Japanese melodies; each Western melody had a Japanese counterpart, although the two melodies of a pair differed with respect to their underlying scales. Otherwise the Western melodies were identical to Japanese counterparts in terms of melodic contour, rhythm, and melody length. A professional Western musician composed the melodies so that each of the Western segments consisted of [doh, re, mi, fa, sol, la, ti]. For each melody (in both musical cultures), two additional in-key tones were added to the end of the original 23-tone melody, such that each melody consisted of 25 tones. A tone in the 24th position of a given melody was fixed as a re or a la in the movable doh solmization, and the 24th tone was the same between each Japanese melody and its corresponding Western melody. The tone in the 25th position was fixed as a sol. In this experiment, Western and Japanese melodies were presented in the three different keys (i.e., tonal centers were C, D, or A#).

In this study, participants rated the extent to which a melody *reflected* “Western music” or “traditional Japanese music” (using a scale from -3 to +3, where -3 reflects a strong sense of traditional-Japanese-music and +3 reflects a strong sense of Western-music). It is pertinent to note here that we have used the word “reflect” in this description; however, to inform our participants we actually used many pointed Japanese words (e.g., familiarity, membership-like, etc. in English) to clarify the aim of ascertaining whether a given melody is perceived as a piece of native Western music or native traditional Japanese music.

We predicted that if these Japanese participants were Western "monomusicals", and not bimusicals, then they should provide ratings consistent with "Western-music-like (0 to +3)" to the Japanese melodies or at least these ratings would not differ from chance levels (i.e., a score of 0). The results showed this was not the case. Japanese participants recognized all Western melodies as "native Western music" (mean=0.69; SD=0.37; range=0.83~1.5), while also recognizing all Japanese melodies as "native traditional Japanese music" (mean= -1.05; SD=0.33; range=-0.38~-1.7). This means that they activated a tonal schema for the Western diatonic scale for the Western melodies and a tonal schema for traditional Japanese scale (i.e., the Ritsu scale) for the Japanese melodies. There was a significant difference between the ratings of Western melodies and those of Japanese melodies [$t(23)=9.37$, $p<.001$]. Moreover, both the ratings for the Western melodies and those for the Japanese melodies significantly differed from the chance level [$t(30)=17.41$, $p<.001$ for Western melodies, $t(30)=10.69$, $p<.001$ for Japanese melodies]. These results indicate that Japanese participants were able to understand both the nature of Western music and the nature of traditional Japanese music and that they could reliably categorize the Western and the Japanese melodies. Even Western monomusicals can distinguish the Japanese melodies from the Western melodies; however, they are not able to understand the Japanese melodies as native traditional Japanese music[1]. Thus, the Japanese participants, and very likely most of the current population of Japan, are truly "Western music and traditional Japanese music" bimusicals.

Finally, we selected 20 Japanese melodies and their 20 Western counterparts as the stimuli for the MEG experiment; these melodies were equivalent in terms of the absolute values of ratings [$t(38)=.81$, $p=.42$]. With these melodies, we could rule out an explanation based on a quantitative difference in the degree of a sense of tonality even if the dipole strength of the mERAN differs between the two cultures.

In sum, our pilot study confirms that Japanese listeners are true bimusicals of "Western music and traditional Japanese music." That is, their brains engage respectively different tonal structures of Western music versus traditional Japanese music. In the present MEG study, we sought to determine which of three hypotheses, temporal, spatial, or activation level, provides the best description for neural differentiations between Western music and traditional Japanese music.

2. Material and methods

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[1] To reaffirm these results, we also presented our Japanese melodies to several Westerners (i.e., non-Japanese) who were unfamiliar with traditional Japanese music. The Westerners reported that they did not recognize the Japanese melodies as "traditional Japanese music" and that they felt a lack of familiarity, i.e., foreignness, in the melodies. Based on these reports, in addition to the findings outlined above, we are convinced that these Japanese participants are bimusicals and not Western monomusicals who are responding to a Western five-tone scale.

2.1. Participants

Participants were 21 native Japanese undergraduate and graduate students (age range: 21 to 45 years, mean=26.5 years, 8 females). None of participants of the MEG study had participated in the pilot experiment. The participants did not have professional or formal musical education, but 13 participants reported performance experience with a musical instrument either as a private hobby or as part of a club or scholastic group. The average year of performance experiences was 3.9 (range of 0 to 12 years). Eight participants played the piano, one participant each played the synthesizer, the electric guitar, the drums, the bassoon, and the flute. None of the participants were currently playing an instrument. In addition, no participants reported receiving formal music education or participating in music performances of traditional Japanese music. As in a bimusical study by Wong et al. (2011), we asked the participants to report the relative percentage of time they listened to a Westernized style of music (i.e., Western pop, Western classical, and Western tonal music sung in Japanese), a non-Westernized style of music (i.e., purely traditional Japanese music), and any other musical genre while growing up (Table 1). Specifically, we instructed participants as follows: “If the total time of music listening from 0 to 12 years of age (or from the age of 12 years to present) is 100%, how do you divide this percentage into five categories (i.e., Japanese pop, traditional Japanese music, Western pop, Western classical, and other).” None of the participants had lived outside of Japan for more than six months before the age of 18. All participants were right-handed and reported normal hearing. Informed consent was obtained from each participant prior to the experiments in accordance with the regulations of the local ethics committee.

2.2. Materials

The stimulus materials consisted of 400 tone sequences based on the 20 Western and 20 Japanese melodies selected in the pilot experiment. In the pilot experiment, we prepared melodies that ended on in-key tones (i.e., sol in the movable doh solmization; e.g., G in a tonal center C; see in-key versions in Fig. 1). In the MEG experiment, however, we prepared not only melodies with in-key ending tones but also melodies with out-of-key ending tones. These melodies were identical to the in-key versions except that the ending tone was an out-of-key tone (i.e., fa# in the movable doh solmization; e.g., F# in a tonal center C; see out-of-key versions in Fig. 1). Both in-key and out-of-key (tonal deviant) versions of all melodies were played in five different keys (i.e., the tonic notes were C, C#, D, A#, or B). A total of 200 tone sequences were derived from Western melodies and 200 were developed from Japanese melodies. Visual inspection of histograms showed that the distribution of the occurrence of each absolute pitch across all Western and Japanese tone sequences was very similar. Each tone sequence was presented once during the experiment. Each sequence consisted of 25 tones; it lasted 3947 ms, with each tone duration lasting 157.9 ms; decay time/tone was approximately 60 ms. That is, the duration of the ending tone was also 157.9 ms. The inter-stimulus interval (ISI) between successive sequences was variable (onsets to offsets ranged from 1000 ms to 1500 ms). All tone sequences were tuned to an equal temperament and were produced using an acoustic grand piano timbre.

In addition to these 400 tone sequences, 40 tone sequences were generated in which the ending tone was played by a deviant instrument (pipe organ). Half of the 40 sequences conformed to the Western diatonic scale, and the other half conformed to the Japanese Ritsu scale.

All tone sequences were created in WAV format using Garageband (Apple Computer), then converted from stereo sound to monaural sound using Audacity Version 1.3.11 (available at audacity.sourceforge.net). All sequences were amplitude-normalized to 65 dB. All sequences were controlled by means of Presentation (Neurobehavioral Systems, Inc., Albany, USA) and presented to listeners, binaurally, using ear tubes.

2.3. Procedure

The participants were not informed as to the nature of the end of the sequence (i.e., the tonal deviant manipulation: in-key versus out-of-key tones). Instead, they were told to listen for a deviant instrument and to respond to this deviant by pressing a button. Prior to the experiment, participants practiced detecting a deviant instrument. Similar tasks have been used in many previous studies (e.g., Koelsch & Jentschke, 2010; Mirand & Ullman, 2007); this task ensured that the participants attended only to an auditory stimulus without requiring them to detect a tonal deviant. By instructing participants to detect instrumental deviations, we prevented the mERAN activity from being obscured due to other non-focal ERFs (e.g., N2b). The Western and Japanese melodies were presented in different blocks and the order of the blocks was counterbalanced across participants. The order of melodies within a block was randomized separately across participants. The participants completed a questionnaire prior to the experiment in order to assess their history of musical training.

2.4. MEG recording, data processing, and analysis

Prior to MEG recording, the geometrical shape of the participant’s head was measured by recording the landmarks (nasion, left and right preauricular points) and a number of representative points on the surface of the scalp using a three-dimensional digitizer (Polhemus Inc., USA). Head shape data were used to obtain for co-registration of dipole source location with a template standard brain.

Continuous, raw MEG signals were recorded using a custom-made, helmet-shaped SQUID system with 76-channel magnetometer sensors (Elekta-Neuromag). The signals were digitized with a bandwidth of 0.03 Hz to 200 Hz at a sampling rate of 600 Hz. The MEG epochs contaminated by artifacts larger than 1500 fT/cm in any of the MEG sensors were rejected on-line from the averaging process. The mean number of accepted trials per block was 97.4/100 trials. Recordings were further processed off-line using Curry (NeuroScan). The data were filtered off-line with a 2-10 Hz band-pass filter, similar to a previous MEG study (Maess et al., 2001). A notch filter at 50

Hz removed power line noise. The data were baseline-corrected based on a 100 ms pre-melody interval.

For each participant and musical culture tested, we modeled the sources of MEG responses using a fitting procedure that estimated the parameters (location, orientation, and strength) of a single equivalent current dipole (ECD) in each hemisphere within the time window of the mERAN. Generally, when conducting a source localization analysis, the use of all sensors may be good in terms of spatial resolution. However, in some cases, analyses based on a subset of sensors estimates a source more accurately than analyses based on all sensors. The rationale for using sensor subsets rests on the following argument: If a source localization analysis is based on all sensors, including ones receiving weak or faint signals relative to noise, then the S/N ratio will be unnecessarily small, leading to a source estimate with a correspondingly low goodness-of-fit value (for a very recent review, see Salmelin, 2010). For this reason, many studies use source analyses based on a subset of sensors (e.g., Helenius, Parviainen, Paetau, & Salmelin, 2009; Liljeström, Kujala, Jensen, & Salmelin, 2005; Pantev, Ross, Berg, Elbert, & Rockstoh, 1998; Papadelis, Poghosyan, Fenwick & Loannides, 2009; Salmelin & Hari, 1994; Salmelin & Sams, 2002). Especially in studies using auditory stimuli, this procedure has been successfully used to localize sources of the auditory responses such as N1m, P2m, and MMNm (e.g., Kuriki, Isahai, & Otsuka (2005) for a musical tone; Brattico, Pallesen, Varyagina, Bailer, Anouroca, Jarvenpaa, Eerola, & Tervaniemi (2008), Tervaniemi, Kujala, Alho, Virtanen, Illmoniemi, & Näätänen (1999) for a musical chord; Elbert, Sterr, Rockstroh, Pantev, Müller, & Taub (2002), Yamashiro, Inui, Otsuru, Kida, & Kakigi (2009) for a pure tone). Therefore, following this practice established in auditory studies, we selected a subset of sensors from all 38 sensors in each hemisphere (i.e., 76 sensors for the whole-head). First, we removed a few sensors that were broken or had contaminated signals. Second, based on visual inspections of both the topography of N1m (in response to the first tone of a melody) and topography of mERAN (in response to the ending tone of a melody), we identified several sensors that received weak or faint signals in comparison to noise. The exact number of removed sensors depended on each participant due to different head position with respect to the sensors. Consequently, in this study, the ECD models were evaluated separately based on a subset of sensors (i.e., more than 25/38 sensors) for each participant's right and left hemispheres. The spherical volume conductor model was used for the source analysis.

We selected dipole models according to the following criteria: (1) the dipole location (in the frontal and temporal areas); (2) the goodness-of-fit (not lower than 60%); and (3) the strength of the response (the strongest mean global field power). The dipoles that met all three criteria had consistent (non-random) angles of orientation. When the ECD models did not fulfill all three criteria, the location and strength parameters for the dipoles were treated as missing values. The statistical literature has recommended that missing values can be individually interpolated when they are not completely random (e.g., Schafer, 1997). Therefore, consistent with the previous MEG studies (e.g., Brattico et al., 2008), we used the expectation maximization (EM) algorithm. The EM algorithm is a general method for finding maximum-likelihood estimates of an underlying distribution from a given data set when the set has missing values (e.g., Bilmes, 1998). Obtained estimates can be assigned to the missing values. In this study, the algorithm was implemented using SPSS Missing Values soft package.

This experiment assessed three hypotheses about mERAN by analyzing, respectively, three different mERAN characteristics: peak latency, the dipole location, and the dipole strength of the mERAN. First, peak latencies of the mERAN were analyzed to test a temporal hypothesis using a paired t-test for both the Western and Japanese conditions. Second, dipole locations of the mERAN were analyzed to test a spatial hypothesis using a one-sample t-test by calculating the distances between the mERAN dipole locations in the two conditions. If the result of the t-test showed a significant difference, the x- (left-right), y- (posterior-anterior), and z-coordinates (inferior-superior) of the dipoles were analyzed separately using two-way ANOVA with the following two within-subject factors: "culture condition" (Western, Japanese) and "hemisphere condition" (right, left). Third, the dipole strengths of the mERAN were analyzed to test an activation level hypothesis using an identical two-way ANOVA design. Moreover, analyses of covariance (ANCOVA) were employed to assess these same three factors (above) using the number of years of music training as a covariate. Many studies have provided evidence that brain activity involved in music processing is modulated by listeners' musical training (e.g., Koelsch, Schmidt, & Kansok, 2002). By performing these ANCOVAs, we attempted to estimate the effect of music training on the mERAN activity involved in tonal differentiation between two cultures. For all of the analyses, the appropriate adjustments to the number of degrees of freedom were made (Greenhouse-Geisser correction) when Mauchly's sphericity test was significant. Post-hoc comparisons were performed using the Bonferroni test.

2. Results

In the main experiment participants detected an average of 98.7% of the deviant instruments, showing that participants reliably detected the timbre deviants and attended to the timbre of the melodies. Hit rates did not differ significantly between the Western (mean=99.3%) and Japanese (mean=98.0%) melodies [$t(20)=.89$, $p=.38$].

In this experiment, we obtained MEG signals from each of four conditions: The in-key and out-of-key versions for both Western and Japanese melodies. For each condition, the mean global field power (MGFP) was calculated by collapsing signals of all MEG channels for all participants. As evident in Figure 2, there are three event-related field (ERF) components common to each condition: One ERF component at 20-100 ms (peak latency = approximately 60 ms), another at 100-160 ms (peak latency = approximately 140 ms), and a third at 230-330 ms (peak latency = approximately 300 ms) after the onset of the ending tone. The strongest MGFP of each component was more than twice as large as the standard deviation of MGFP calculated within the prestimilus baseline interval (-100 ~ 0 ms). Although each of the three ERF components seemed different in terms of both the peak latency and the MGFP strength among the four conditions, these differences were not confirmed by statistical analyses. For each of the three ERF components, the peak latency with the strongest MGFP was examined using a one-way ANOVA with a within-subject factor (the four conditions). Results of these analyses showed no significant differences among the four conditions for all three components ($p>.1$). Likewise, for each ERF component, analysis of the strongest MGFP data showed no significant differences among the four conditions ($p>.1$).

Next, we examined the three ERF components (i.e., the ERFs at 60 ms, 140 ms, and 300 ms) to determine which component reflected a specific response to tonal processing. The 60 ms component can be interpreted as the P1m on the basis of its peak latency and the magnetic field map. The P1m is a general auditory-evoked field response and is elicited in response to auditory stimuli, such as music, pure tones, and speech. The magnetic field maps of the 300 ms component were not consistent between individuals, rendering interpretations problematic. On the remaining 140 ms component, its peak latency and amplitude pattern were consistent with those described previously for ERP/ERF reflecting the tonal processing. The peak latency of the 140 ms component was within the time window of 125-150 ms. The amplitude of the component in several of front-temporal channels on each participant was larger for out-of-key tones than in-key tones (Fig. 3), although there was not significant differences in MGFP (averaged over all channels and all participants) between out-of-key and in-key conditions. According to the explanation provided by Koelsch and Siebel (2005), the greater amplitude for out-of-key tones results from increased computational load in the processing of a tone not included in the listener’s tonal schema. As mentioned in Introduction, in this paper we labeled the ERP/ERF reflecting tonal processing as (m)ERAN; thus, hereafter the 140 ms component will be referred to as the mERAN.

Because results from the analyses of the 60 ms and 300 ms components were not systematically different among the four conditions, the analyses presented below were computed using the mERAN field generated by out-of-key tones. Next, we report the results of analyses aimed at ascertaining the viability of each of the three hypotheses based upon different aspects of the mERAN properties (i.e., the peak latency, the dipole strength, and the dipole location) were clearly different between the Western and Japanese conditions.

3.1. mERAN peak latency and the temporal hypothesis

Peak latencies of the mERANs elicited by the out-of-key tones in the Western and Japanese conditions were 143 ms and 146 ms, respectively. These results are consistent with those of previous studies investigating Western monomusicals’[2] responses to out-of-key tones in Western tone sequences. The previous studies have found that the peak latency of the (m)ERAN is

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[2] Although participants of the previous studies are not specifically identified as Western monomusicals, participant descriptions leave no doubt that they are monomusicals.

approximately 125-150 ms (e.g., Koelsch & Jentschke, 2010; Paller et al., 1992; Verleger, 1990).

If the temporal hypothesis is correct and a temporal aspect of the mERAN is critical, then peak latency should explain the sensitivity of brain activity to the differentiations of the two culture-specific tonal structures. Thus, a difference between the mERAN peak latencies for the Western and Japanese conditions should be observed. For each Western and Japanese condition, the time point with the strongest MGFP was treated as the peak latency of the mERAN. A t-test revealed no significant difference between the two conditions [$t(20)=.73$, $p=.47$]. This indicates that a difference in this temporal feature of the mERAN did not contribute to the tonal differentiation between Western and Japanese cultures. Therefore, we can reject the temporal hypothesis.

3.2. mERAN dipole location and the spatial locus hypothesis

Dipole solutions for the mERAN in response to the out-of-key tones were obtained for each participant in each of the Western and Japanese conditions. The averaged goodness-of-fit values across the dipoles that fulfilled the three criteria (i.e., dipole location, goodness-of-fit, and the strength of the MGFP) were 63-96% (mean=82%) for the Western and 60-97% (mean=82%) for the Japanese conditions.

To assess the spatial hypothesis, dipole location data were transformed into a Talairach-sized standard brain and averaged across participants. The resulting dipole locations are shown in Fig. 4. By comparing the standardized Talairach space, we observed that both of the mERAN dipoles for the Western and Japanese conditions were located within the inferior frontal gyrus (IFG) of the right hemisphere and within the premotor cortex (PMC) of the left hemisphere. Note that when a source localization analysis is conducted, a standard brain, co-registered using the head sharp data (e.g., digitized location of nasion and preacricular points) of each participant, leads to larger errors than revealed in the individual MRI brain image of each participant. This fact requires us to caution that the locations of the obtained dipoles do not correspond precisely to absolute anatomical locations within the brain. Therefore, any conclusions regarding differences in the location between neighboring regions observed in this experiment, such as the IFG and PMC, should be considered less reliable. Despite these limitations, we concluded that the dipoles resulting from the Western and Japanese conditions were generated from approximately the same brain regions (i.e., around the IFG/PMC). This interpretation is consistent with the results from previous studies of Western monomusicals, which have shown that the IFG is activated during tonal processing (e.g., Kolesch et al., 2005; Maess et al., 2001; Minati et al., 2008; Wehrum et al., 2011). Moreover, the approximate anatomical locations identified for the mERAN dipoles were validated by our computations of the dipole fit for the P1m field (i.e., the 60 ms component), which revealed that the dipoles of the P1m for both Western and Japanese conditions were located in the superior temporal gyrus (Fig. 4).

If the spatial locus hypothesis is correct, we expect that a difference in the spatial location of brain activity will contribute to a differentiation of culture-specific tonal structures. That is, the mERAN dipole locations for Western and Japanese conditions would differ. To test this hypothesis, we analyzed the distances between the mERAN dipoles for the Western and Japanese conditions for the left and right hemispheres separately, with the null hypothesis corresponding to zero distances. Distances were calculated from the formula $[(x_1-x_2)^2 + (y_1-y_2)^2 + (z_1-z_2)^2]^{1/2}$, where x, y, and z denote the location points of the dipoles on x-, y-, and z-coordinates, respectively. The subscripts 1 and 2 indicate the Western and Japanese conditions, respectively. In both the left and right hemispheres, the results of a t-test revealed that the distances were significantly different from zero [Right, $t(20)=11.35$, $p<.001$; Left, $t(20)=9.82$, $p<.001$].

To identify which coordinates of the dipole locations contributed to distance differences, the x-, y-, and z-coordinates of the dipoles were analyzed separately using 2 (culture) x 2 (hemisphere) ANOVAs. First, for the x-coordinate, an ANOVA revealed a significant culture x hemisphere interaction [$F(1, 20)=6.51$, $p<.05$, partial eta squared=.25]. The simple main effect showed that in the right hemisphere only, the mERAN of the dipole for the Western condition was generated medially to that of the Japanese condition [$F(1, 20)=6.75$, $p<.05$]. This difference was not observed in the left hemisphere. Second, with regard to the y-coordinate, ANOVA revealed no main effect or interaction. Finally, with respect to the z-coordinate, ANOVA revealed a main effect of culture [$F(1, 20) =3.63$, $p=.07$, partial eta squared=.15], indicating that the mERAN dipole for the Western condition was located superior to that of the Japanese condition.

To summarize, locations of the mERAN dipoles for the Western and Japanese conditions did not completely overlap; rather they differed spatially within the same brain region around the IFG/PMC. The different brain subregions that were activated, respectively, during the Western and Japanese melodies likely contribute to a differentiation of the two culture-specific tonal structures. This means that the spatial hypothesis cannot be rejected.

3.3. mERAN dipole strength and the activation level hypothesis

Fig. 5 shows the dipole strength of the mERANs for the Western and Japanese conditions. The laterality index was calculated from the formula $(R - L)/(R + L)$, where R and L denote the strengths of the dipoles located in the right and left hemispheres, respectively. Based on this definition, the index ranges between 1 and -1, with positive values indicating right lateralization and negative values indicating left lateralization. The laterality indexes were 0.19 for the Western condition and -0.09 for the Japanese condition. The only index that exhibited a marginally significant difference from zero was that of the Western condition [$t(20)=1.84$, $p=.08$]. These results indicate an asymmetric strength between the right and left hemispheres for the Western condition and a symmetric strength for the Japanese condition. Moreover, in light of the unbalanced number of participants of each gender, we conducted the same t-test separately for a male group and female group. The results suggested that, although neither group showed a bias in the Japanese condition, the male group alone did exhibit a bias toward the right hemisphere in

Western condition [$t(12)=3.12$, $p<.01$]. The results of hemispheric weighting of the mERAN, including the gender difference, are consistent with those of the Western monomusical studies (e.g., Koelsch, Maess, Grossmann, & Friederici, 2003)

If the activation level hypothesis is correct, then we would expect to find a difference in the degree of brain activation as a function of Western and Japanese tonal structure. The latter is assessed by mERAN dipole strength; that is, dipole strengths estimated for Western and Japanese conditions should differ. To test this hypothesis, 2 (culture) x 2 (hemisphere) ANOVA was performed. The result revealed no main effect and no interaction between these variables ($p>.1$). Thus, the difference in the degree of brain activation induced by Western and Japanese music did not contribute to the tonal differentiation between the two cultures.

3.4. Results of ANCOVA

In order to estimate the effects of music training on the each of three mERAN characteristics (i.e., the peak latency, the dipole location, and the dipole strength), we performed ANCOVAs separately for each characteristic. The ANCOVAs included years of musical training as the covariate. The results of the all characteristics revealed no significant effect of the musical training ($p>.1$), but we again found the same effects and interaction, as reported above.

4. Discussion

Results showed that the mERAN activity was elicited by tonal deviations in both Western music and traditional Japanese music. Moreover, common brain regions --- the inferior frontal cortex in the right hemisphere and premotor cortex in the left hemisphere were the main source location of the mERAN activity for Western music and that for Japanese music. Three different characteristics of mERAN were considered in the formulation of three hypotheses. Respectively, these hypotheses focused upon temporal, spatial, and activation level characteristics of the mERAN. The present results revealed that the spatial locus hypothesis, not temporal and activation level hypotheses, best described the nature of mERAN brain activity responsible for differentiating Western tonal structure from Japanese tonal structure. Specifically, the dipole location estimated for Western tonal structure and that for Japanese tonal structure were separated from each other within IFG/PMC areas.

In suggesting that the dipole location differences are relevant to the differentiations of tonal structures between Western and Japanese music, we must consider the possibility that the mERAN overlaps with the N1m/P2m. In this study, subtle differences in melodic properties (e.g., number of scale tones, the pitch interval between the penultimate and antepenultimate tones) were found between Western and Japanese melodies. Such differences in properties may elicit different N1m/P2m fields between the two cultures, and as a result, the N1m/P2m fields might differentially affect the dipole source localization of the mERAN. To examine this possibility, we estimated the extent that the mERAN and the N1m/P2m overlap. Specifically, we observed the N1m/P2m in response to the first tone because the first tone elicited the clearest N1m/P2m. The peak latency of the N1m was approximately 110 ms after the onset of the first tone, and this was significantly earlier than that of the mERAN (i.e., 140 ms peak) [Western, $t(20) = 7.72$, $p < .001$; Japan, $t(20) = 11.73$, $p < .001$]. On the other hand, the P2m was not observed prior to 157.9 ms, which was the onset of the second tone. This means that the P2m would be elicited after 157.9 ms. Based on the statistical results showing that the peak latency of the mERAN was significantly different from 157.9 ms [Western, $t(20) = 3.32$, $p < .01$; Japan, $t(20) = 3.12$, $p < .01$], the P2m, which would be elicited after 157.9 ms, did not overlap with the mERAN. To the best of our knowledge, no study has reported that the peak latencies of the N1m/P2m change with the presentations of successive tones. Thus, even if the N1m/P2m and mERAN overlapped, it is unlikely that effects of the N1m/P2m extended beyond residual error. Accordingly we can conclude that the N1/P2 are negligible contributions to the dipole source localization of the mERAN.

In summary, the observed difference in dipole location within the IFG/PMC is likely to contribute to the differentiation between Western tonal structure and traditional Japanese tonal structure. Many studies of Western monomusicals have shown that the processing of Western tonal structure activates the inferior frontolateral cortex more strongly in the right than in the left hemisphere (e.g., Koelsch, Gunter, et al., 2002; Koelsch et al., 2005; Maess et al., 2001). The present study extends these findings in Western monomusicals by revealing that the processing of Western tonal structure and that of traditional Japanese tonal structure in bimusical brains activate common regions, specifically those around the IFG/PMC. Moreover, the present findings clearly indicate that the cortical representation for the Western tonal structure and that for the traditional Japanese tonal structure are spatially separated within the IFG/PMC; this suggests that the neural function of the brain region around the IFG/PMC is differentially developed due to listeners having acquired two distinct tonal schemas.

Based on these results, it will be important to determine the nature of spatial relationships between the brain subregions (i.e., within the area around the IFG/PMC) which appear to underlie differentiation of tonal structures between Western and traditional Japanese music. One possibility is that the brain subregion representing Western tonal structure is completely separate from that representing Japanese tonal structure. Another possibility is that the brain subregions representing Western tonal structure and that representing Japanese tonal structure, while partly overlapping, are separate.

Studies of bilinguals that focus on a question analogous to that posed here for bimusicals have reported that the brain regions responsible for their native language and a second language primarily overlap in bilinguals who acquired a second language early in life and/or were highly proficient bilinguals. However, these regions appear to be separated in bilinguals who acquired their second language later in life and/or were not highly proficient bilinguals (e.g., Kim, Relkin, Lee, & Hirsch, 1997; Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003).

Given that we have borrowed from the findings of bilingual studies in showing that ELAN, the linguistic equivalent of ERAN (e.g., Koelsch, 2009), is not observed in low proficient bilingual speakers (e.g., Rossi, Gugler, Friederici, & Hahne, 2006), the results of the present experiment suggest that our participants are not accurately described as “low” proficient bimusicals in each of Western and Japanese music. Moreover, our participants reported that they were familiarized with both Western and Japanese music from an early developmental stage (Table 1). In other words, our participants can be considered as early and fully proficient bimusicals. Taken together, when comparing the characteristics of our bimusical participants with those of bilinguals, it appears unlikely that the brain subregion representing Western tonal structure can be *completely* separated from the brain subregion representing Japanese tonal structure. Some overlap may be possible. In any case, future investigation of the brain activity involved in the tonal differentiation between two cultures should focus on the spatial locations of this brain activity. This implies that such studies should use not only MEG but also techniques that have higher spatial resolution, such as fMRI.

It is also important to explore, in greater detail, aspects of tonal processing that determine the spatial differentiation of neural generators associated with Western versus traditional Japanese music. Three explanations for determinants of this spatial separation are possible: the specific property of tonal schema, the order of tonal schema acquisition, and proficiency level of music. First, given the melodic controls employed here, it is possible that spatial segregation in the brain reflects certain defining properties within tonal schemas (i.e., the Western diatonic tonal schema vs. the traditional Japanese tonal schema), which are at the heart of processing of tonal structure. The simplest interpretation involves the number of scale tones within the tonal schema between the traditional Japanese scale and the Western diatonic scale. Another (more likely) interpretation involves the psychological hierarchy of scale tones. Specifically, the perfect fifth between doh and sol (e.g., C and G in a tonal center C) plays a dominant role in the Western tonal schema (e.g., Krumhansl, 1990), whereas the perfect fourth between doh and fa (e.g., C and F in a tonal center C) plays a dominant role in the traditional Japanese tonal schema (e.g., Koizumi, 2009).

Second, spatial segregation in the brain may arise from processes related to acquiring tonal schemas. That is, one of the two tonal schemas must have been learned first; hence possibly the initially acquired scheme occupies a priority location in the IFG/PMC. This idea has been described in brain studies on bilinguals (e.g., Kim et al., 1997). Relatedly, with respect to the actual age at which acquisition occurs, studies of bilingual individuals have reported that both the age of acquisition and the proficiency level strongly influence brain activity (e.g., Chee, Soon, & Lee, 2003; Kim et al., 1997; Perani, Paulesu, Galles, Dupoux, Dehaene, Bettinardi, Cappa, Fazio, & Mehler, 1998; Wartenburger et al., 2003). However, in considering parallels between bilinguals and bimusicals, the present study has no information to suggest differences due to age of acquisition of tonal schemas. All participants in this study reported they were exposed to both Western and traditional Japanese music before the age of 12. Therefore, we cannot firmly ascertain the order of acquisition of a given tonal schema nor can we pinpoint the influence of acquisition age on bimusicals' brain activity.

Third, spatial segregation in the brain may depend on a listener's musical proficiency. In general, listeners acquire more highly structured tonal schema as they develop more proficiency in the music of a given culture (e.g., Trainor & Trehub, 1992, 1994). Considering the fact that, in general, Japanese listeners have largely spent more time listening to Western music than to traditional Japanese music (Abe & Hoshino, 1990), a difference in proficiency level would be present between two cultures and this difference may be reflected in the spatial segregation. Although the experimental design of the present study cannot examine this possibility directly, we may have obtained indirect information that pertains to effects of proficiency level. Our participants differed in musical training years, and we performed ANCOVAs with the number of years of music training as a covariate. With regard to this variable, the resulting measurements of dipole location of the mERAN indicated that the effect of music training was not statistically significant. However, another interpretation for the insiginificant effect of Western music training is possible. Our participants reported that they had listened mostly to the Westernized style of music from the age of 12 (years) onward; furthermore, Japanese students are required to take Western music classes for nine years through elementary school and junior high school (according to the Japanese government guidelines for education, 473 hours for 9 years). Based on such music backgrounds, the negligible effect of Western music training on spatial locations may be explained by a ceiling effect.

In any case, findings of the present study alone are not sufficient to differentiate between explanations based upon specific property of tonal schema, age acquisition or proficiency level. Hopefully, these issues will be addressed by future research on bimusical brains.

5. Conclusion

This study provides the first MEG-based evidence indicating that the differences in the spatial location of neural activation, rather than differences in either a temporal property or the strength of this activation, contribute to bimusicals' abilities of differentiation of the two culture-specific tonal structures. This evidence suggests that brain area responsible for the processing of tonal structure is located around the inferior frontal cortex/premotor cortex and can be functionally differentiated by exposure to two distinct musical cultures.

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