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MEG study of music processing in bimusicals

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Abstract. Many studies with monomusical Western listeners have shown that tonal processing is mainly handled in the inferior frontal cortex. However, very little is known about the neural mechanisms of bimusicals. We exaimed whether two distinct music traditions (music of home culture, music of foreign culture) elicited differnt brain activity and involved a different brain area in bimusicals. The magnetoenchphalographic (MEG) responses were recorded when “Western diatonic music-Japanese traditional music” bimusicals heard out-of-key tones in either Western diatonic melodies or Japanese traditional melodies. The out-of-key tones elicited an early negativity with a peak latency of approximately 140 ms (N140m), but there was no difference in the latency and amplitude of the N140m peak for the Western diatonic melody as compared to that for the Japanese traditional melody. Moreover, there was no difference in the location and strength of the dipole source of N140m for the two types of melody. That is, two distinct music traditions were processed with equal strength in a common brain area, putatively the inferior frontal cortex. These results suggest that, regardless of distinct music traditions, activation of the inferior frontal cortex in “Western music-Japanese traditional music” bimusicals was roughly similar to that in Western monomusicals.

Keywords: music perception, tonal organization, scale schema, bimusicality, magnetoencephalograph.

1. Introduction

Tonal organization is essential for music perception [e.g., Krumhansl, 1990]. This organization assigns a coherent tonal relationship between the pitches of the individual notes in the sequence, and as a result a sense of key or tonality is perceived. A substantial literature suggests that listeners, even those without formal musical training, establish the tonal organization according to their “scale schema” which is acquired through exposure to the music of their culture [e.g., Matsunaga and Abe, 2005, 2008]. This idea is supported by the evidence that listeners perceive a tone sequence that is more assimilated into their own scale schema as a “tonal” melody [e.g., Matsunaga and Abe, 2005, 2008]. Also, listeners can easily detect a pitch that is not assimilated into their own scale schema [e.g., Trainor and Trehub, 1992].

In recent years, the neural mechanisms that underlie tonal organization processing have been investigated. Many studies showed that a tonal inappropriate pitch (i.e., a pitch deviating from a scale) in a tone sequence [Brattico, Tervaniemi, Näätänen, and Peretz, 2006; Koelsch and Jentschke, 2009; Miranda and Ullman, 2007] or a harmonically inappropriate chord in a chord sequence [Maess, Koelsch, Gunter, and Friederici, 2001] elicits an early right anterior negativity (ERAN). The ERAN is thought to specifically be an auditory evoked potential or an auditory evoked magnetic field effect in response to a violation of the tonal (or harmonic) structure in music. It is thought to rely on scale schema, not physical features [Koelsch, 2009]. It is shown that the ERAN is usually maximal at somewhere between 100-250 ms (100~200 ms for a tone, 150~250 ms for a chord) [Koelsch and Jentschke, 2009] and is modulated by musical experiences [Jentchke and Koelsch, 2009]. A more intriguing finding was provided by an MEG study of Kolesch and his colleages [Maess, et al., 2001]. They showed that the main generator of the ERAN is located in the frontal inferior cortex, especially Broca’s area which is known to be involved in the processing of language syntax. This finding was confimred by subsequent fMRI studies [e.g., Koelsch, Fritx, Schulze, Alsop, and Schlaug, 2005] and studies with brain-damaged patients [e.g., Sammler, Koelsch, and Friedrici, 2010].

However, these previous findings are limited to Western monomusicals. That is, the findings may only explain monomusicals who acquire Western diatonic scale schema incorporating knowledge of harmonic structure, a Western-culture-specific elaboration of pitch that is quite recent in music history. In musical cultures such as those in Japan and South Korea, listeners have been enculturated into two music traditions (e.g., Western diatonic music and Japanese traditional music for Japanese) such that they acquire two different scale schemas. They are called bimusical. Very little is known about the neural mechanisms underlying tonal organization processing of bimusicals. In this paper, we examined whether the bimusical brain process the two distinct music traditions (i.e., the distinct scale schemas) differently.

We measured the magnetoencephalogram (MEG) responses of "Western diatonic music-Japanese traditional music" bimusical non-musicians when they heard an out-of-key tone at the ending of melodies. This experiment employed melodies conforming to either the Western scale or the Japanese traditional scale. In the Western music, the diatonic scale [*do-re-mi-fa-sol-la-si*] is basically used. In contrast, scales used in Japanese traditional music are four types: Minyo, Miyakobushi, Ritsu, and Ryukyu. Here, we selected the Minyo scale [*do-re#-fa-sol-la#*] and the Ritu scale [*do-re-fa-sol-la*]. In the pilot study, we ensured the validity of our Western diatonic melody materials and our Japanese traditional melody materials. To explore the similarities and differences in brain activities between Western diatonic scale schema and Japanese traditional scale schema, this experiment was designed to compare brain responses to out-of-key tones in Western diatonic melody type with those in Japanese traditional melody type.

2. Methods

2.1. Participants

Fourteen native Japanese (21 to 34 years old; five female) participated in this experiment. All were either graduate or undergraduate students. None of them had formal education at a music conservatory or academy. Although some of them had discontinuously received a private lessons in Western classical music (mean 3.7 years of practice), all self-reported they were non-musicians. None reported having absolute pitch. They were right handed. Informed consent was obtained for each participant prior to the experiments in accordance with the regulations of the local ethical committee.

2.2. Materials

The materials for this study were based on 20 Western diatonic melodies and 20 Japanese traditional melodies. These Western melodies and Japanese traditional melodies were chosen on the basis of the results from our pilot study. All were monophonic isochronous melodies whose tones were contiguous without overlaps. All melodies consisted of 25 tones. In all melodies of each music tradition, the last tone and the second last tone were constant. The melodic contour of each Western melody and that of each Japanese melody were identical. The duration of each tone was 157.9 ms, for a total of 3947 ms per melody. All melodies were created in WAV format with Garageband (Apple), and then converted from stereo sound to monaural sound with Audacity Version 1.3.11.

We created two versions of each melody by manipulating a pitch at the last position of the melody: producing an in-key version and an out-of-key version. The in-key version served as a control comparison, and all constituent tones of this version conformed to a certain key. In the in-key versions of all melodies, a tone chroma *sol* (i.e., A in D major) occurred at the last position. On the other hand, the out-of-key version had a pitch deviating from a scale. In this version, a tone of the last position of all melodies was changed to a pitch deviating from the scale, i.e., a tone chroma *fa#* (i.e., G# in D major). Thus, materials consisted of 20 Western diatonic melodies and 20 Japanese traditional melodies, with in-key and out-of-key versions for each. All materials were played in five different keys (C major, C# major, D major, A# major, B major), thus a total of 400 melodies were prepared.

In addition to those 400 melodies, we prepared 40 melodies in which the final tone was a timbre deviate. For these melodies, the timbre of the last tone was a pipe organ. Half of them conformed to the Western scale, and the other half conformed to the Japanese traditional scale. They were used only to provide participants with an easy detection task (see below).

2.3. Procedure

Participants were not informed about an in-key ending or out-of-key tone ending. Instead, they were informed about the deviant timbre ending, and asked to respond to such an ending by pressing a button. This task has already been used in many previous studies [e.g., Koelsch and Sammler, 2008] and allowed us to control for the participants only attending to an auditory stimulus, but not detecting an out-of-key tone.

Western materials and Japanese materials were presented in different blocks, counterbalanced across participants. The experiment took about 38 min. Before the experiment, participants completed a questionnaire that assessed their musical background.

2.4. MEG recording and data analysis

The continuous raw MEG was recorded using a custom-made helmet-shaped SQUID system with 76-channel magnetometer sensors (Elekta-Neuromag, Helsinki). Signals were digitized with a bandwidth of 0.03 Hz to 200 Hz and a sampling rate of 600 Hz. Recordings were further processed off-line using Curry (NeuroScan). Data were filtered off-line with a 2-10 Hz band-pass filter, in line with a previous MEG study [Maess, et al., 2001]. A notch filter at 50 Hz was also applied to assure the removal of the power line noise. Data were baseline-corrected on the basis of a 100 ms pre-stimulus interval.

For each participant and melody type, we modeled the sources of the magnetic responses by means of a fitting procedure that estimated the parameters of an equivalent current dipole (ECD). The ECD models were evaluated on the basis of a selection of about 25 channels above the frontal and temporal areas separately for each participant's right and left hemispheres. We selected the dipole models according to the goodness of fit (better than 60%). In six participants, the dipole sources for the auditory evoked magnetic field (AEF) effects on out-of-key tones could not be modeled well in either the right hemisphere or the left hemisphere because AEF effects were weak, consequently, the goodness of fit was quite low. Therefore, the location and strength parameters for the low goodness-of-fit dipoles were instead individually calculated using the expectation maximization (EM) algorithm. This treatment of missing values has been employed in other studies [e.g., Brattico, Pallesen, Varyagina, Bailey, Anourova, Järvenpää, Eerola, and Tervaniemi, 2008]. Each ECD location was plotted onto the standard brain prepared in Curry. The PAN coordinate system was used. This coordinate system is defined via the preauricular points and the nasion of the participant.

3. Results and Discussion

All participants detected every of the trials with timbre deviation.

3.1. Auditory evoked magnetic field (AEF) effect

Visually, brain responses elicited from out-of-key tones in Western diatonic melody type and those in Japanese traditional melody type were very similar. Fig. 1 (a) shows the mean global field power (MGFP) signal for out-of-key tone endings for both melody types. Two kinds of AEF effects were observed before around 250 ms. The first AEF effect emerged at around 60 ms, probably P1m. The second AEF effect emerged around 100~120 ms after the onset of the out-of-key tone and peaked at around 140 ms (142.83 ms for Western melody, 140.9 ms for Japanese melody) --- hereafter in this study we have named it N140m. There was no significant difference in the MGFP signal of the N140m between the Western melody and the Japanese melody, $t\,(13) = 1.10$, *ns*. (MGFP was calculated for each participant separately in the time window from 100~180 ms.)

The field maps of the N140m for the Western melody and those for the Japanese melody were also very similar. In both cases, a relatively clear dipolar pattern over each hemisphere was observed (Fig. 1 (b)).

The N140m in response to out-of-key tones in both Western melody and Japanese melody seems equivalent to the ERAN that previous studies indicated as an electrophysiological marker for tonal organization processing. However, there is one concern: does that N140m merely reflect a basic auditory evoked magnetic field N1m? This question arises because the N1m has a similar field map pattern and nearly the same peak latency. To examine this possibility, we compared peak latencies of N140m (collapsed between the two types of melody) and those of N1m. Brain responses elicited by in-key tone endings were supposed to serve as a control comparison in this experiment, but, unexpectedly, the N1m evoked by in-key tone endings was very small. This might be due to the rapid succession of tones [Hari, Hämäläinen, Ilmoniemi, Kaukoranta, Reinikainen, Salminen, Alho, Näätänen, and Sams, 1984]. Hence, in this study we focused on the N1m elicited by tones at the first position of melodies across the two types of melody. Specifically, as a previous MEG study did [Maess, et al., 2001], we combined the N1m evoked by the first tones of out-of-key versions with those of in-key versions in order to achieve a higher signal-to-noise ratio. Peak latency of the N140 (141.9 ms) was significantly longer than that of N1m (112.9 ms), $t(13)=8.8$, $p < 0.001$. This result supports the idea that N140m is a different AEF component from a basic auditory evoked magnetic field (N1m), suggesting that it is the equivalent of the ERAN. That is, N140m reflects tonal organization processing, i.e., processing based on scale schema. In short, in spite of the distinct scale schemas, tonal processing elicited common neural activities in bimusical brains.

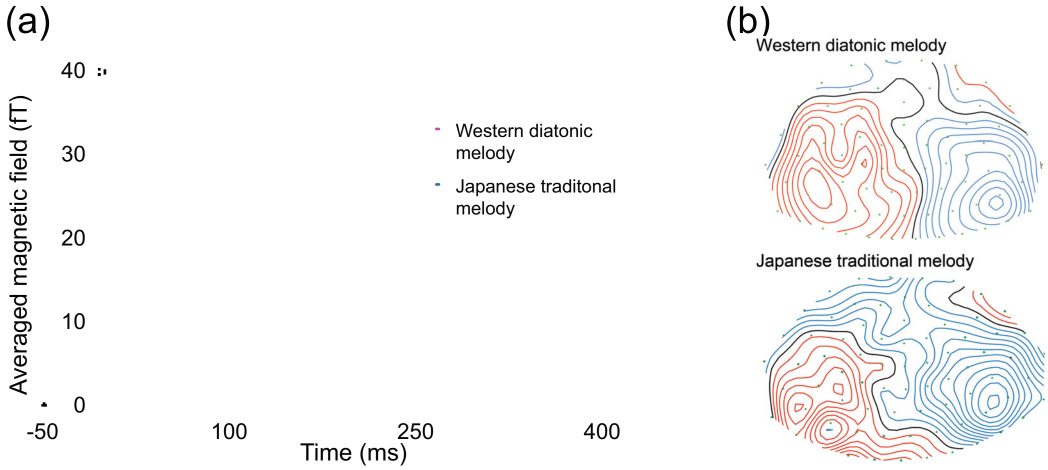

Figure 1. *(a) Mean global field power signals of the N140m (MGFP averaged over all MEG channels and all participants). Zero corresponds to the onset of out-of-key tones at the last location of a melody. (b) Magnetic field map of N140m for the Western diatonic melody and that for the Japanese traditional melody. These two maps are from one participant.*

3.2. Dipole solutions

Dipole solutions for the N140m for the Western diatonic melody type and for the Japanese traditional melody type were obtained from each participant (Fig. 2). For both the *y*- and *z*- coordinates of dipoles, there was little to distinguish the location of the dipole of N140m for the Western melody from that for the Japanese melody. The *y*- and *z*- coordinates of dipoles were separately submitted to ANOVAs with Culture (Western vs. Japanese) and Hemisphere (left vs. right) as repeated factors. ANOVAs for both *y*-coordinate and *z*-coordinate did not reveal any main effect and interaction. This means no location difference for the main generator of N140m in Western melodies and that for Japanese melodies. Moreover, the two-way ANOVA for dipole strength did not reveal any main effect and interaction, indicating no strength difference of N140 source between Western melody type and Japanese melody type in both hemispheres (left hemisphere = 3.4 and 4.5 μ Amm, right hemisphere = 5.3 and 4.6 μ Amm, for Western melody and Japanese melody, respectively). These results suggest that tonal organization based on Western scale schema and that on Japanese scale schema involved a common brain area with equivalent strength.

In this experiment, the standard brains were used. This prevented us from directly pointing out the specific name of brain regions that generated the N140m. Therefore, we tried to estimate the specific name of bran areas generating N140m by comparing the location of the primary auditory cortex that is thought to generate N1m. The dipole of N140m was located approximately anteriorly (16 mm for left hemisphere, 11 mm for right hemisphere) and superiorly (6 mm for left; 13 mm for right) with respect to the dipole of the N1m (Fig. 2). The *y*- and *z*- coordinates of dipoles were separately submitted to ANOVAs with Component (N1m vs. N140m) and Hemisphere (left vs. right) as repeated factors. ANOVA for the *y*-coordinate yielded a main effect for Component, $F\ (1, 13) = 5.04$, $p < 0.05$. This result means that the main source of N140m was significantly anterior to that of N1m in each hemisphere. On the other hand, ANOVA for the *z*-coordinate revealed a main effect for Component, $F\ (1, 13) = 4.84$, $p < 0.05$, and a interaction between Component and Hemisphere, $F\ (1, 13) = 7.90$, $p < 0.05$. Results of the simple effect showed that in the right hemisphere, the dipole of N140ms was located superior to that of N1m, $F\ (1, 26) = 9.37$, $p < 0.01$; in the left hemisphere, the dipole of N140m was located slightly superior to that of N1m, but the difference was not statistically significant.

The results for the location of the dipole source showed that the generators of N140m were located anteriorly and superiorly with respect to the generators of the N1m. This result is consistent with those of Maess et al (2001). Maess et al. showed that the main source of brain responses (i.e., ERAN) in response to tonal/harmonic inappropriate chords was located approximately 25 mm anterior to and 10

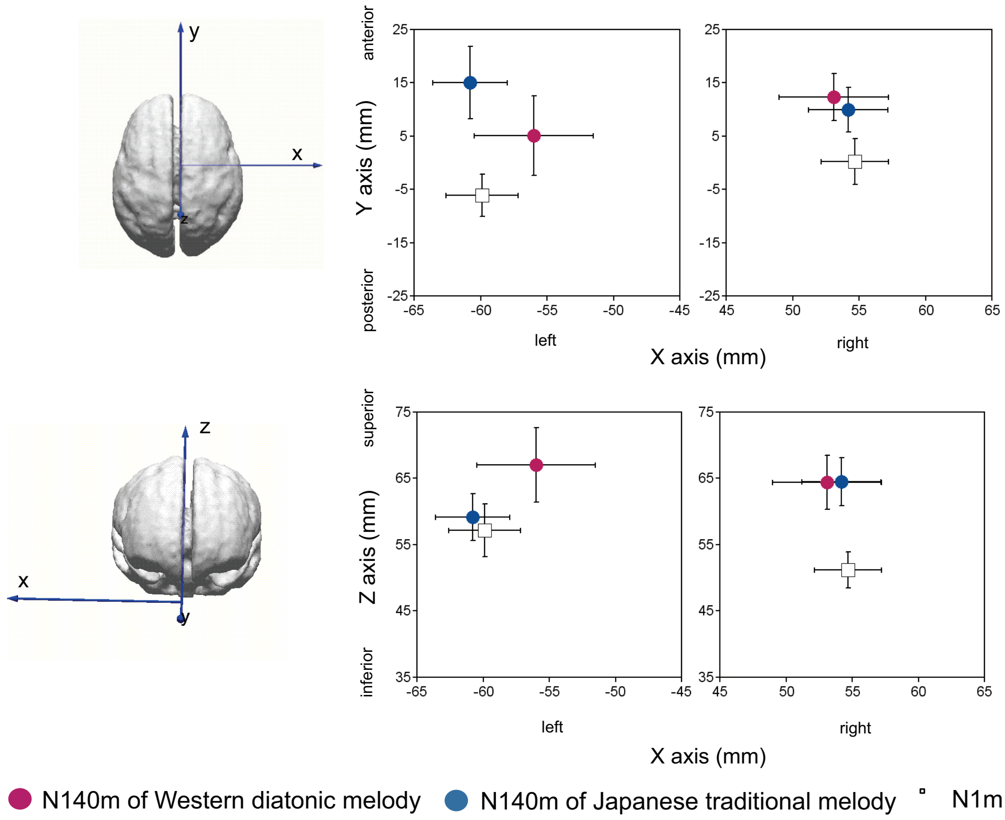

Figure 2. *Mean ECD locations for the N140m for the Western diatonic melody and the Japanese traditional melody, and mean ECD location for the N1m. In this PAN coordinate system, the positive x axis goes through the left preauricular point and the negative x axis goes through the right preauricular point; the negative y axis goes through the nasion; the z axis is 90 degrees from both the x and y axes and starts at their intersection.*

mm superior to the primary auditory cortex, and that the source location of ERAN corresponds to the inferior frontal cortex. The relative distance and the relative orientation of the N140m dipoles compared to the primary auditory cortex are compatible between their results and our results. Thus, we can be allowed to infer that the main generator of N140m in our study was within the inferior frontal cortex.

4. General Discussion

The results of the AEF effect showed that for both the Western diatonic melody type and the Japanese traditional melody type, out-of-key tones elicited an early AEF effect that was maximal around 140ms (N140m). There was no difference in the latency and amplitude of peak for N140m between the two types of melody. Moreover, the results of the ECD solution revealed that the location and strength of the dipole of N140m for the Western diatonic melody did not significantly differ from that for the Japanese traditional melody. On the basis of the consistency with the results of Maess et al (2001), the putative source location of N140m was within the inferior frontal cortex. Taken together, the results of the present study suggest that, despite of different scale properties, tonal organization based on the Western diatonic scale schema and that on the Japanese traditional scale schema involve the same brain area (putatively, the inferior frontal cortex) with equivalent strength. The results parallel those from bilingual studies, which show that the first language and the second language are fundamentally processed in the common neural recruitment [DeGroot, 2011 for a review].

In our pilot study, we confirmed that the general Japanese university students are able to differentiate between the two distinct types of music materials of this experiment. This in turn rules out one potential interpretation for the results of this experiment, namely that the same brain activity between Western melody and Japanese traditional melody was merely due to participants' differentiation failure. After all, the results of this experiment imply that bimusical participants achieved the different psychological outcomes (i.e., tonal interpretations based on Western scale schema vs. those on Japanese scale schema) via the same activity of inferior frontal cortex. On the basis of the results, it can be supposed that the inferior frontal cortex is “musical scale-independent” part of neural network involving tonal organization processing. In other words, two scale schemas of the bimusicals may access a common tonal processing system that be represented in the inferior frontal cortex.

Our results reveal that the early negativity response and the involvement of the inferior frontal cortex are very similar for the tonal processing of bimusicals compared to that for monomusicals. However, on the other hand, we found that there were small but interesting differences. First is a peak latency difference. In our study, bimusicals’ responses to out-of-key tone endings of tone sequences peaked at approximately 140 ms; in previous studies, monomusicals’ responses to out-of-key tone endings of tone sequences peaked at approximately 125ms [Koelsch and Jentschke, 2009]. That is, the peak latency of the bimusical was slightly later than that of the monomusical. Second is the lateralization difference. In our study, bimusicals showed no lateralization for the brain response to out-of-key tone endings (i.e., no difference of dipole strength between right and left hemisphere); in many previous studies, monomusicals showed right lateralization [Koelsch, 2009]. These differences may argue for further studies that would directly compare bimusicals and monomusicals.

In any case, our findings provide the initial empirical data for the neural mechanism underlying tonal processing of bimusicals. Bimusicals are not a very small select group; and, the population of bimusicals will increase as the globalization of music increases. Bimusicalism may provide a research tool for probing deeper questions about the nature of music perception and of related brain mechanisms.

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