NeuroReport 10, 999–1002 (1999)

Musicians with absolute pitch show distinct neural activities in the auditory cortex

Yoshihiro Hirata,[CA] Shinya Kuriki and Christo Pantev[1]

Research Institute for Electronic Science, Hokkaido University, Kita 12, Nishi 6, Kita-ku, Sapporo, 060-0812, Japan; [1]Institute of Experimental Audiology, Wilhelms University of Münster, Kardinal-von-Galen-Ring 10, 48129 Münster, Germany

[CA]Corresponding Author

MEG responses from musicians who had absolute pitch and from non-musicians were measured while they received differnt auditory stimuli. The parameters of single equivalent current dipoles (ECDs) were calculated for the N1m responses occurring in the auditory cortex. The location of the ECD for the noise burst was significantly posterior to the ECDs for the tones in the two hemispheres of the musicians, but not for those of the non-musicians. Further, in the left hemisphere the ECDs for the musicians were significantly posterior to those for the non-musicians. These results suggest distinct neural activities in the auditory cortex of musicians, which may be the result of cortical plasticity produced by training and/or an inherent cortical structural specificity. *NeuroReport* 10:999–1002 © 1999 Lippincott Williams & Wilkins.

Key words: Absolute pitch; Auditory cortex; Musician; N1m; Magnetic fields; Magnetoencephalography (MEG); Plasticity

Introduction

Daily musical training, as used by professional musicians to increase their skill level, increases neuronal activity in the somatosensory cortex of the fingers of string players [1]. It is also thought that musical training in childhood is important in the acquisition of absolute pitch, a kind of special musical skill [2] with which one can recognize or sing any note without musical cues. This ability has been examined mainly by neurophysiological studies in which event-related potentials, especially the P300 component, were recorded for exploring cognitive strategies of musical perception [3,4]. On the other hand, an anatomical study using magnetic resonance imaging (MRI) showed that musicians who possess absolute pitch have strong leftward asymmetry of their planum temporale, a posterior part of the auditory cortex situated in the temporal lobe [5]. This finding indicates that musicians with absolute pitch have a larger left planum temporale than do those who do not possess absolute pitch. Pantev *et al.* examined the N1m component of the auditory evoked field peaking at about 100 ms after stimulus onset from the left hemisphere in both musicians and non-musicians in a passive listening experiment [6]. They found that in musicians the dipole moments of N1m for piano tones were about 25% greater than those for pure tones of frequencies similar to the fundamental frequencies of the piano tones. This phenomenon was not observed in the control subjects, who had never played any instrument. Their observations suggest plasticity by musical training in the auditory cortex. However, their study was restricted to the left hemisphere.

In the present study, we sought to clarify functional differences in the neural activity of the auditory cortex between well-trained musicians with absolute pitch and controls without absolute pitch, extending the MEG examination to the left and right hemispheres with piano tones and noise sounds as auditory stimuli presented in an active odd-ball pradigm.

Subjects and Methods

Eleven Japanese female college students majoring in music (age 20–22 years), all except one of whom specialized in the piano, and who had been practicing from the age of 3–5, participated in this experiment. The subjects claimed to have absolute pitch, the possession of which was confirmed by a greater than 90% correct response to a screening procedure in which they were asked to identify 50 different piano tones. For comparison, 11 female college students (age 19–22 years) who had never practiced on any instrument participated in the same experiment. All 22 subjects reported no history of hearing loss or neurological disorder, and were right-handed (the Edinburgh handedness questionnaire [7]). Informed consent was obtained from all subjects. The musicians with absolute pitch are hereafter referred to as AP subjects, and the non-musicians as non-AP subjects.

Five different sounds, four tones and a noise burst (NB), were used as auditory stimuli. The tones included the commonly known musical notes C4 (fundamental frequency of 263 Hz), C6 (1057 Hz), and E6 (1324 Hz), and a pure tone C5p which has the same frequency as the fundamental frequency of the piano tone C5 (520 Hz). The piano tones were digitally recorded from a piano, and the C5p tone and NB were synthesized with a computer to have the envelopes resembling the piano tones C5 and C7, respectively (Fig. 1). The NB had uniform frequencies between 200 and 400 Hz. An odd-ball paradigm was used in order that the subjects could pay attention to the auditory stimuli during MEG measurements. The subjects listened to a series of randomly presented sounds, during which they counted the incidence of the highest tone (E6). The target stimulus (E6) occurred 120 times, while the non-target stimuli (C4, C5p, C6, and NB) were presented 300 times each in individual recording. All stimuli were presented monaurally at 60 dB SPL (sound pressure level) with randomized interstimulus intervals (ISI) between 1.35 and 1.65 s.

MEG measurements were carried out with a 19-channel SQUID magnetometer system installed in a magnetically shielded room [8]. A 3SPACE Fastrak (Polhemus Inc., USA) was used to digitize several reference points on the subject's head, from which a head-frame-based coordinate system was designed. In this system, the x-axis was directed toward the nasion from the origin at the midpoint between the right and left preauricular points, the y-axis toward the left preauricular point, and the z-axis toward Cz. The stimuli were presented to the lower side of the ear using an earphone while subjects were lying on their left or right side on a bed. MEG responses were measured above the upper side of their head, where the recording was made twice on each side, at sensor locations that differed slightly in the anterior–posterior direction. The recorded MEG data were collected into epochs of 700 ms duration, including a 300 ms pre-trigger, and 250–300 epochs to each tone (except E6) and NB were separately averaged and digitally filtered below 20 Hz. In order to evaluate the peak latency and amplitude of the N1m component, root mean square (RMS) values of all (two recordings $\times$ 19) channel responses were calculated for each hemisphere of the subject and for each stimulus. Single equivalent current dipoles (ECDs) were calculated for the N1m component using the two-recording sets of the MEG data. The calculated ECDs were selected on the basis of a goodness-of-fit (GOF) $> 90\%$, an index of agreement between the observed and calculated magnetic fields, and stability of the calculated single ECD in position over 10 ms latencies. The dependent variables, N1m parameters (location and strength of the ECD) and the N1m peak latency, were analyzed for each group using a two-way analysis of variance (ANOVA) for the four sound types (C4, C5p, C6, NB) $\times$ two hemispheres (left *vs* right). A two-tailed *t*-test was used to examine the differences between the two groups.

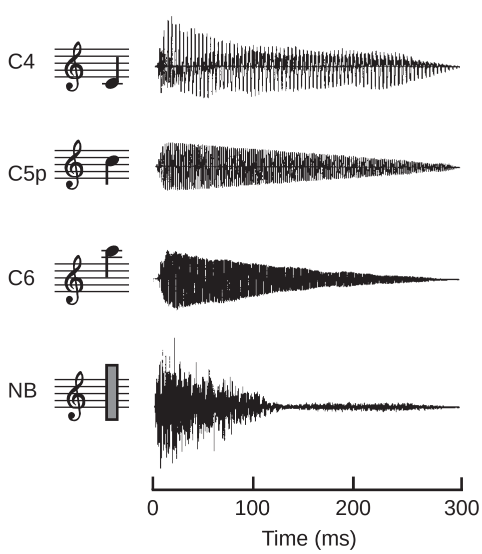

FIG. 1. The waveforms of auditory stimuli. C4 and C6 are digitally recorded piano tones. C5p is a pure tone with the fundamental frequency of the piano tone C5. NB is a noise burst with an envelope which resembles the piano tone C7.

Results

Clear N1m responses were observed in 10/11 left and 8/10 right hemispheres measured for AP subjects, while clear N1m responses were observed in 9/10 left and 9/10 right hemispheres measured for non-AP subjects. The N1m responses for the NB were weak in some subjects, and did not yield 90% of GOF.

The ANOVA for the N1m latency of AP and non-AP subjects revealed a significant main effect of the stimulus type ($F(3,18) = 12.29$, $p < 0.0001$, and $F(3,18) = 12.19$, $p < 0.0001$, respectively), but no significant main effect of the hemisphere or in the interaction of these independent variables. *Post hoc* Scheffé's testing revealed that the peak latency of C6 was significantly shorter than that of the other sounds in both groups (C6–C4 $= -7.0 \pm 1.2$ ms, C6–C5p $= -8.0 \pm 1.5$ ms, $p < 0.001$, C6–NB $= -5.4 \pm 1.6$ ms, $p < 0.03$ for AP subjects; and C6–C4 $= -7.7 \pm 1.5$ ms, C6–C5p $= -5.9 \pm 1.2$ ms, $p < 0.001$, C6–NB $= 2.9 \pm 1.2$ ms, $p < 0.17$ for non-AP subjects). The ANOVA for the RMS amplitude revealed a significant main effect of the stimulus type ($F(3,18) = 13.0$, $p < 0.0001$ for AP subjects; $F(3,18) = 15.56$, $p < 0.0001$ for non-AP subjects), but no significant main effect of the hemisphere or in the interaction of these independent variables. *Post hoc* Scheffé's testing revealed that the RMS amplitude of N1m for NB was significantly smaller than that of the other sounds ($p < 0.01$ for non-AP subjects, and $p < 0.001$ for AP subjects). Similar to the results for RMS amplitude, the ECD moment of the NB was significantly smaller than that of the other sounds in both groups ($F(3,18) = 8.40$, $p < 0.0011$ for AP subjects; $F(3,18) = 13.57$, $p < 0.0001$ for non-AP subjects). When the ECD moments were compared between pure tone and piano tones, there were no statistical differences in AP subjects and also in non-AP subjects.

Figure 2 shows average ECD locations across subjects in each group, projected on the x-y (axial) plane of the MEG coordinates, where an axial MR image of one subject is illustrated to indicate the spatial range of the ECDs in the anatomical structure. The ANOVA for the x-coordinate (anterior–posterior position) of the ECDs revealed a weak main effect of the hemisphere for the AP subjects ($F(1,6) = 5.43$, $p < 0.056$), but no significant difference for the non-AP subjects ($F(1,6) = 0.34$, N.S.); the average x-coordinate in the left hemisphere of the AP subjects was about 6 mm posterior to that in the right hemisphere. For the ECD location on the stimuli, the ECDs for the NB were located significantly to the posterior (about 4 mm) in the x-coordinate of the ECDs for the other tones in both hemispheres of the AP subjects ($F(3,30) = 11.50$, $p < 0.0001$). There were no significant differences in the y- and z-coordinates, while for non-AP subjects the ECD locations for different stimuli were not significantly different in any direction in either hemisphere.

Compared with the ECD locations between two groups, the ECDs of the AP and non-AP subjects were very close to each other and were not significantly different ($p < 0.14$, *t*-test) in any direction in the right hemisphere. In the left hemisphere, however, the ECDs of the AP subjects were located 6 mm to the posterior of those of the non-AP subjects. This separation was significant ($p < 0.005$) in a two-sample *t*-test.

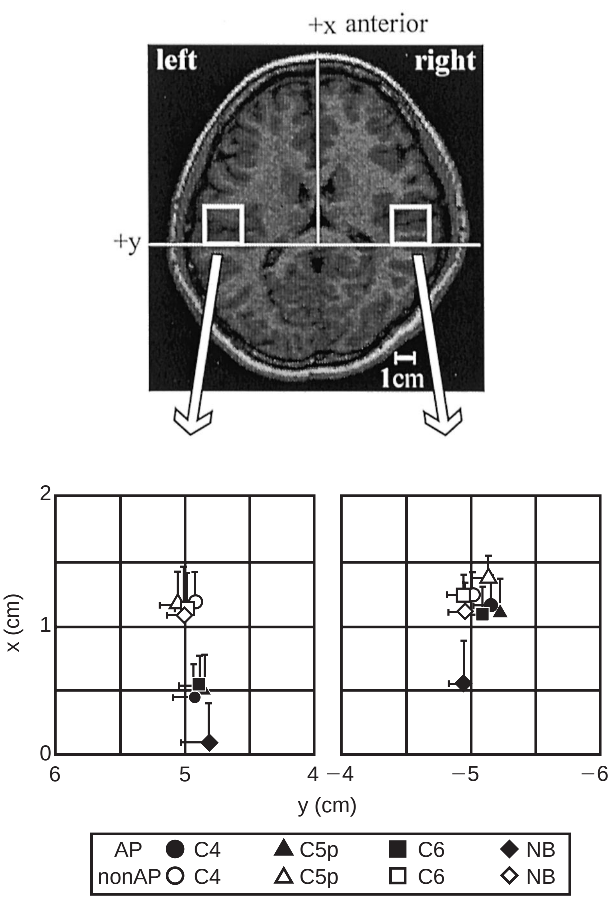

FIG. 2. Average ECD locations across subjects in the AP and non-AP groups, projected on the x-y plane of MEG source coordinates, where horizontal and vertical bars indicate s.e.m. An axial MR image ($z = 6$ cm) of one AP subject is illustrated to indicate the spatial range of the ECDs.

Discussion

In previous MEG studies on the N1m responses to different auditory stimuli it was observed that neural activity in the left hemisphere occurs about 1 cm posterior to that in the right hemisphere [9,10]. The posterior shift of the ECDs is compatible with the anatomical asymmetry proved by Geschwind and Levisky [11], who showed that the planum temporale on the superior surface of the temporal lobe, i.e. posterior part of the auditory cortex, is larger in area and longer posteriorly by an average of 9 mm in the left than in the right hemisphere. Some MEG studies reported, however, that there was no inter-hemispheric difference in the position of N1m activity in normal female subjects [12,13], suggesting a gender difference in anatomical structure. Similarly, our observations in the present study found that in non-AP female subjects there was no significant difference in the location of the ECDs in any direction between the left and right hemispheres. On the other hand, in AP female subjects an inter-hemispheric difference was found, with the left ECDs 6 mm to the posterior of those of the right hemisphere.

Further and most importantly, the left-hemisphere ECDs in the AP subjects were significantly posterior to the left ECDs in the non-AP subjects. These findings seem to correspond to the anatomical enlargement of the planum temporale toward the posterior direction revealed by MRI for musicians having absolute pitch [5]. Thus, in addition to the anatomical asymmetry, our study also confirmed the presence of functional asymmetry of neural activities in the auditory cortex of musicians with absolute pitch. We suggest that musicians with absolute pitch may have distinct neural processing of musical tones in the left auditory cortex. Whether this is the result of cortical plasticity induced by training or is an inherent structural specificity of the auditory cortex, or both, is a topic for further studies.

A posterior shift of the ECDs for NB to the ECDs for the other tones was observed in both hemispheres of the AP but not the non-AP subjects. The waveform of the NB sound used in this experiment (Fig. 1) is characterized by sharp and random spikes that may be the source of high frequency spectrum. According to the MEG study by Kuriki *et al.* [14,15] on the N1m responses to monosyllabic speech sounds, plosive- and fricative-vowel sounds elicit N1m activities in the auditory cortex that are posteriorly and laterally shifted to those elicited by vowel and nasal-vowel sounds. Kaukoranta *et al.*, [16] also observed no significant difference between the location of the N1m activities elicited by a noise burst and by words which have a fricative onset. Considering that plosive, fricative and noise burst contain high frequency components, the results of the above mentioned studies indicate that complex sounds having high frequencies tend to be processed in the more posterior part of the planum temporale. Thus, our observation of the posterior neural activity for noise burst in the AP subjects suggests that musicians, who practice instruments intensively, are highly sensitive to high frequency components or steep temporal changes in auditory sounds.

Contrary to the report by Pantev *et al.* [6], in this experiment no statistical difference between the dipole moments for piano tones and the pure tone were found in the AP subjects. The major reason for this difference is probably that they adjusted the intensity of the piano tones and the corresponding pure tone stimuli to the same hearing level of 60 dB HL, while in this study the stimulus intensity was fixed to 60 dB SPL. An additional factor is that they used a passive listening paradigm with a long ISI of 3–4 s, while we used an odd-ball paradigm including selective attention with a much shorter interstimulus interval.

Conclusion

The present study was conducted for two groups (AP and non-AP), who were homogeneous in age (19–22 years), gender (female) and handedness (right-handed). The average ECD locations of the non-AP subjects were found in a narrow spatial range (within a $21 \times 12 \times 13$ mm cube in the x, y, and z axes) of the two hemispheres for the different tones and the NB, with no inter-hemispheric difference in their locations. The average ECDs of the AP subjects were also located in a narrow range (within a $19 \times 9 \times 17$ mm cube) of the two hemispheres for the tones, but the ECD for the NB was located significantly to the posterior. Further, these ECDs had hemispheric asymmetry with a left-side posterior shift. These observations suggest distinct neural activities in the auditory cortex of well-trained musicians who possess absolute pitch. Such peculiar activity may be the result of the cortical plasticity of auditory neurons or an inherent structural specificity of the auditory cortex, as revealed previously by MRI [5] and MEG [6] studies.

References

1. Elbert T, Pantev C, Wienbruch C *et al. Science* **270**, 305–307 (1995).
2. Bachem A. *J Acoust Soc Am* **11**, 432–439 (1940).
3. Shigeno S. *Percept Psychophys* **54**, 682–692 (1993).
4. Crummer GC, Walton JP, Wayman JW *et al. J Acoust Soc Am* **95**, 2720–2727 (1994).
5. Schlaug G, Jäncke L, Huang Y and Steinmetz H. *Science* **267**, 699–701 (1995).
6. Pantev C, Oostenveld R, Engelien A *et al. Nature* **392**, 811–814 (1998).
7. Oldfield RC. *Neuropsychologia* **9**, 97–113 (1971).
8. Hirata Y and Kuriki S. *IEICE Trans Electron* **E79C**, 1213–1218 (1996).
9. Reite M, Teale P, Zimmerman J *et al. Electroencephalogr Clin Neurophysiol* **70**, 490–498 (1988).
10. Elberling C, Bak C, Kofoed B *et al. Acta Neurol Scand* **65**, 553–569 (1982).
11. Geschwind N and Levitsky W. *Science* **161**, 186–187 (1968).
12. Scheuneman D, Teale P, Linnville S *et al. Brain Res Bull* **26**, 747–751 (1991).
13. Hajek M, Huonker R, Boehle C *et al. Biol Psychiatry* **42**, 609–616 (1997).
14. Kuriki S and Murase M. *Exp Brain Res* **77**, 127–134 (1989).
15. Kuriki S, Okita Y and Hirata Y. *Exp Brain Res* **104**, 144–152 (1995).
16. Kaukoranta E, Hari R and Lounasmaa OV. *Exp Brain Res* **69**, 19–23 (1987).

ACKNOWLEDGEMENTS: The authors are grateful to Dr Hideko Higuchi at Hokkaido University of Education, Sapporo, for her help finding subjects. Part of this research was supported by Grant-in-Aid for Scientific Research 10780522 from the Ministry of Education, Science, Sports and Culture and the Deutsche Forschungsgemeinschaft.

**Receivd 26 January 1999;
accepted 2 February 1999**