N100m in children possessing absolute pitch

Hiroyuki Hirose,[CA] Masaya Kubota, Ikumi Kimura, Masato Yumoto[1] and Yoichi Sakakihara

Departments of Pediatrics; [1]Laboratory Medicine, Faculty of Medicine, the University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8655 Japan

[CA]Corresponding Author: hirose-h@kb3.so-net.ne.jp

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We recorded the auditory evoked magnetic fields from children with and without absolute pitch under the following conditions: (a) hearing 1000 Hz pure tones inattentively, (b) hearing eight random tones inattentively and (c) listening to eight random tones and identifying each tone. We calculated the appearance rate of N100m as the ratio of the subjects who had N100m. There was a significant positive correlation between the appearance rate of N100m and age in both groups. There was also a significant positive correlation between the appearance rate of N100m and the kinds of the task only in children without absolute pitch. These results suggest that, in the children with absolute pitch, N100m was elicited equally in every session because of their automatically driven auditory attention. No significant correlation was found between the appearance rate of N100m and the possession of absolute pitch. *NeuroReport* 14:899–903 © 2003 Lippincott Williams & Wilkins.

Key words: Absolute pitch; Auditory evoked neuromagnetic field; Children; Magnetoencephalography; N100m

INTRODUCTION

The musician's brain has attracted much interest from scientists and many findings have been reported relating to functional plasticity, anatomical differences, audio-motor integration and maladaptive plasticity [1]. Musicians have different cognitive abilities from non-musicians. Recently developed techniques in the neuroimaging, such as fMRI [2], transcranial magnetic stimulation (TMS) [3] and MEG [4] have detected unique cognitive abilities in musicians. Absolute pitch (AP) is one ability which is nearly limited to the musicians. AP is a cognitive ability to identify any tones (labeling) at a given pitch without using any external references [5]. The prevalence of AP is generally estimated to be $< 0.01\%$ [5]. However, the prevalence of AP in professional musicians is in the range of 10–15% and, it is markedly higher among Asian music students at 32.1–47.5% [6–8]. In addition to educational influence, familial aggregations of AP and a genetic predisposition to the development of AP have also been reported [7,8].

An auditory evoked field (AEF) component, N100m, the magnetic counterpart of the electrophysiological N100, represents the most prominent and stable peak of the AEF, which appears at about 100 ms after the stimulus onset. The source of the N100m was considered to be located around the auditory cortices along the bilateral superior temporal gyri [9–11].

There have been several neuroimaging studies on AP possessors. Pantev *et al.* [12] recorded a left N100m from musicians with AP, musicians without AP and non-musicians without AP. They reported that, in the musicians, the dipole moments of the left N100m for piano tones were about 25% greater than those for pure tones and suggested that there was a plasticity in the auditory cortex which was attributable to musical training but not to the AP possession itself. Hirata *et al.* [13] recorded N100m from musicians with AP and non-musicians without AP. They found that the dipole of the left N100m of the AP musicians was significantly deviated posteriorly, compared with those of the non-musicians. They suggested distinct neural activities in the left auditory cortex of musicians, which may be the result of cortical plasticity [14]. Zatorre *et al.* [15] measured the cerebral blood flow during the presentation of musical tones to AP possessors. They showed that not only the superior temporal gyrus but also several other areas, e.g. left dorsolateral frontal region, played important roles in pitch perception in the AP possessors. Ohnishi *et al.* [16] reported in their fMRI study that the AP musicians showed left dominant secondary auditory areas and the left posterior dorsolateral prefrontal cortex during a passive music listening task, whereas non-musicians demonstrated right dominant secondary auditory areas. Concerning event-related potentials, Klein *et al.* [17] reported that the P300 in the AP possessors was smaller than that in the non-AP possessors in an auditory oddball task with 1000 and 1100 Hz pure tones. Hirose *et al.* [18], however, showed that the AP possessors exhibited similar P300 as the non-AP possessors in an auditory oddball task with A4 (440 Hz) and C4 (262 Hz) pure tones. Schlaug *et al.* [14] and Keenan *et al.* [19] showed an increased leftward asymmetry of the planum temporale (PT) in AP musicians from volumetric MRI studies. They suggested that there was a functional asymmetry in the brain of the AP possessors, especially in the superior temporal planes [14,19]. Keenan [19] also reported that the pruning of the right PT rather than expansion of the left PT underlined the increased PT asymmetry in the AP musicians.

These studies were, however, all performed in adult AP possessors. There have been no neuroimaging studies in children possessing absolute pitch and the physiological mechanism in children possessing absolute pitch remains to be clarified. In the present study, we recorded, for the first time, the MEG responses from children possessing absolute pitch while they were labeling. We recorded MEG responses under three different conditions described below. Our hypothesis was that the appearance of N100m was influenced by the difference of the tasks, the age and the AP possession. We hypothesized that the N100m was elicited more strongly as the task became complex and the subjects became elder. Furthermore, we hypothesized that the N100m was more strongly elicited in the AP subjects than non-AP subjects.

MATERIALS AND METHODS

Twelve Japanese children possessing absolute pitch (five males and seven females, aged 7–12 years, average 10.3 ± 1.5 years) participated in this study. They all received early musical education and started to play piano at the age of 3–4 years. For comparison, 2 age- and sex-matched Japanese children without absolute pitch (five males and seven females, aged 8–15 years, average 11.2 ± 2.3 years) participated in the same study. They did not receive early musical education. Before the measurements, a randomized sequence of 60 pure tones between C2 and C6 (averaged pitch, $C2 = 65.5$ Hz and $C6 = 1048$ Hz) was presented to the subjects. A subject was formally labeled as an AP possessor if 80% of the tones were correctly identified. We think that the present AP ability test was difficult for the child subjects so we used an easier criteria for the AP ability than in the adult subjects, as Hirose *et al.* previously reported [18]. None of the subjects had a history of neurological or audiological disorders and they were all right-handed. The entire study was approved by the Ethics Board of the University of Tokyo. Written informed consent was obtained from each subject.

The magnetic fields were recorded under the following three conditions: (a) single tone session consisted of one kind of pure tone (1000 Hz), when subjects were requested to hear the tones inattentively; (b) ignoring session, consisting of eight different pure tones ($p = 0.125$) ranging from C4 to C5 (262–524 Hz, averaged pitch) which subjects were requested to hear inattentively. In the single tone and ignoring sessions, the subjects were instructed to stare firmly at a black point (diameter 1.5 cm) on the wall 2 m ahead of them and requested not to pay attention to the tones. At this stage, because they had not been informed of the following labeling session beforehand we considered their intentional process for labeling the tones was absent or minimal. (c) The labeling session consisted of the same tones as the ignoring session but subjects were requested to listen to the tones attentively and label each tone. Each session consisted of 200 sequential tones and the three sessions were conducted in that order in all subjects. The tones were generated using a personal computer (Physio-Tech Co., Ltd., Japan) and were presented binaurally with randomized interstimulus intervals (ISIs) of 1.00 ± 0.1 s. The duration of each tone was 200 ms, including a 10 ms rise and fall time, and its intensity was 90 dB sound pressure level (SPL). The tones were sine curve tones without overtones.

Each subject sat in a chair in a magnetically shielded room and the magnetic fields were recorded with a 204-channel whole head neuromagnetometer (Neuromag Ltd., Finland). The recording passband was 0.1–200 Hz and the sampling rate was 591 Hz. The automatic rejection level of 3000 fT/cm was applied. Electro-oculograms were recorded and epochs above 150 µV were eliminated online. The measurements from 50 ms before to 600 ms after stimulus onset were averaged 150–200 times. A low-pass filter was used at 40 Hz and a high-pass filter was used at 2 Hz in the offline analysis. A single dipole model was applied. Equivalent current dipole (ECD) was calculated from 30–40 adjacent temporal channels for the N100m component of the auditory evoked field peaking about 100 ms after the stimulus onset, using an iterative least squares minimization algorithm.

To superimpose the estimated sources of N100m on MRI, the position of each subject's head was determined by measuring magnetic fields produced by four marker coils attached to the scalp. Before the measurements, the locations of the coils in relation to cardinal points of the head (nasion, left and right pre-auricular points) were determined using an Isotrak 3D digitizer (Polhemus Inc., USA). Multiplanar head 3D-MRIs were obtained with a Sigma 1.5 T MRI system (GE Medical Systems, USA).

If the ECD for an N100m was calculated in the condition of the goodness-of-fit (GOF) $> 90\%$ and to be located around the auditory cortex, we judged the N100m to be positive. If the GOF was $< 90\%$ and/or the ECD was not located around the auditory cortex, we judged the N100m to be negative. The appearance rate of N100m was defined as the ratio of the numbers of the subjects who had the N100m to the total number of the subjects. We examined the relations between the appearance rate of N100m and the age of the subjects, the kinds of tasks and the possession of the AP ability.

RESULTS

N100m was not clearly elicited in all child subjects in every session. Figures 1 and 2 show examples of the magnetic fields of representative children possessing absolute pitch recorded from temporal sensors that showed N100m clearly and no N100m, respectively. Figure 3 shows the relationship between the appearance rate of N100m and the age in all sessions. Both in children possessing absolute pitch ($p < 0.05$, Spearman's rank correlation coefficient) and those without absolute pitch ($p < 0.05$, Spearman's rank correlation coefficient) there was a significant positive correlation between the appearance of N100 and age.

Figure 4 shows the relationship between the appearance rate of N100m and the kinds of task. In the children without absolute pitch there was a significant correlation between the appearance of N100m and the kinds of task ($p < 0.05$, $3 \times 2\chi^2$ test). In the children possessing absolute pitch, however, there was no significant difference between the

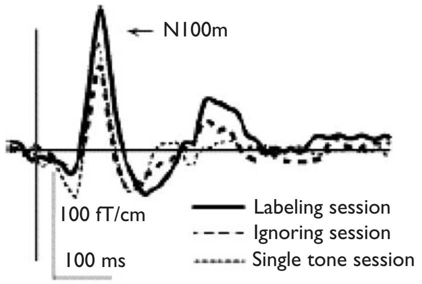

Fig. 1. An example of the magnetic fields of representative children possessing absolute pitch recorded from the right temporal sensors that showed N100m most strongly.

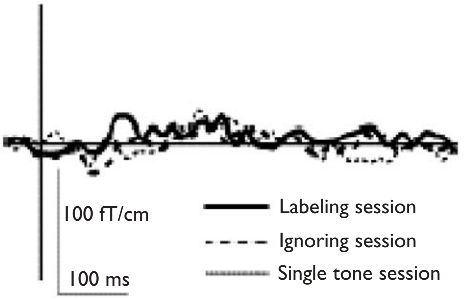

Fig. 2. An example of the magnetic fields of representative children possessing absolute pitch recorded from the right temporal sensors that showed no N100m.

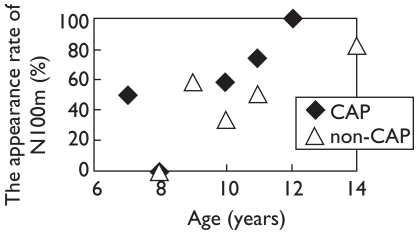

Fig. 3. The relationship between the appearance rate of N100m and the age. In both children possessing absolute pitch and those without there was a significant positive correlation between the appearance rate of N100m and age.

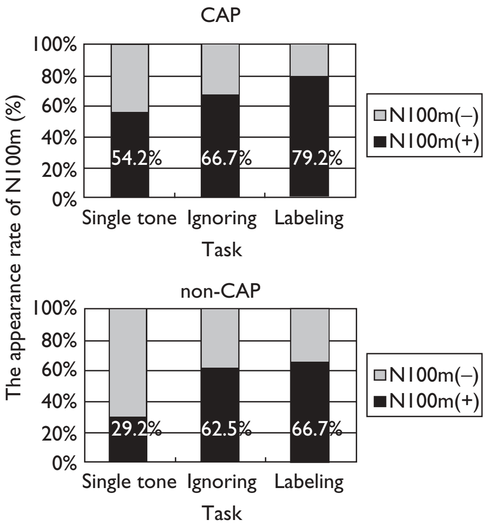

Fig. 4. The relationship between the appearance rate of N100m and the kinds of task. In the children without absolute pitch (bottom), there was a significant correlation between the appearance rate of N100m and the kinds of task. In the children possessing absolute pitch (upper), however, there was no significant difference between the appearance rate of N100m and the kinds of task.

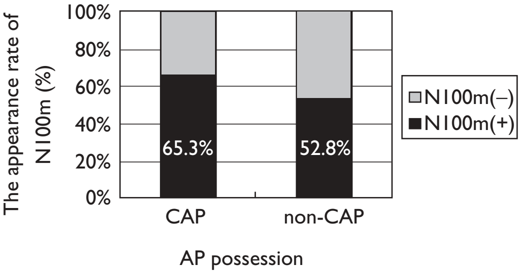

Fig. 5. The relationship between the appearance rate of N100m and the possession of AP. There was no significant correlation between the appearance rate of N100m and the possession of AP.

appearance of N100m and the kinds of task ($p = 0.3$, 3×2 χ^2 test).

Figure 5 shows the relationship between the appearance rate of N100m and the possession of the AP ability in all sessions. There was no significant correlation between the appearance of N100m and the possession of AP ($p = 0.13$, χ^2 test).

DISCUSSION

The main findings of the present study on the child N100m were its ontogenetic nature, the relation to the kinds of task and the possession of the AP ability. Firstly, there was a significant positive correlation between the appearance rate of N100m and age. Previous studies showed that the appearance rate of N100 increased with age [20,21]. Sharma *et al.* [21] showed that the appearance rate of N100 was 61% in 6–7-year-olds, 63% in 8–9-year-olds, 69% in 10–12-year-olds and 100% in 13–15-year-olds. In the present study, the appearance rate of N100m was 75% in 11-year-old children possessing absolute pitch and 50% in 11-year-olds without absolute pitch (Fig. 3). These results are in agreement with those of previous studies and may be a reflection of the fact that underlying myelinogenesis and synaptogenesis proceed at varying rates in different individuals [22].

A significant correlation between the appearance rate of N100m and the kinds of task was shown only in the children without absolute pitch. The single tone and ignoring tasks were the same in the sense of passive listening for the subjects but different in the kinds of tone. As the kinds of tone were increasing, the firing of neuronal populations might well be stronger. This was the case only with those without absolute pitch, however. The N100m in the children possessing absolute pitch was elicited in the similar strength and appearance rate among three tasks. This showed that the auditory cortices were activated enough to elicit the

N100m strongly even in the single tone task. This suggested that even when the kind of tone was single and there was no requirement to label the tone, the auditory cortices in the children possessing absolute pitch were activated similarly as in the more complex tasks. This might be because their auditory cortices had a lower threshold to the tones, or higher sensitivity to the tones. The children possessing absolute pitch received early music training from the age of 3–4 years and their auditory cortices had been much more activated than that in those without absolute pitch, which could endow the children possessing absolute pitch with such higher sensitivity. Thus, the basic plasticity in the auditory cortices in the children possessing absolute pitch might be developed in this way.

The ignoring and labeling tasks were the same in the kinds of tone, but the requirement to the subjects was different. The labeling task required more from the subjects and it was natural that the labeling task elicited the N100m more strongly. This was not the case in the children possessing absolute pitch, however. Hillyard *et al.* [23] showed that more attended stimuli arouse an increased N100 response because the stimuli were selected for later processing. If the N100m appeared more strongly in the labeling task this might be partly because more attention was paid in the labeling task. In the children without absolute pitch, the labeling task was most complex and the most attention was needed of the three tasks, thus, the N100m was most strongly elicited. In contrast, in the children possessing absolute pitch, the N100m appeared similar among three tasks. The appearance rate of the N100m of the children possessing absolute pitch in the single tone task was higher (54%) than that in children without absolute pitch (29%) and this was not significantly different from the rates in other tasks of the children possessing absolute pitch (67% in ignoring task, 79% in labeling task). The attention levels of the children possessing absolute pitch were, therefore, constantly high in the three tasks and it is suggested that common strategies were employed for the three tasks. Thus, the N100m might be equally elicited in the children possessing absolute pitch.

Although the N100m was similarly elicited in the children possessing absolute pitch, we can suggest another way in which neuronal populations in these children are also sufficiently activated, even in the single tone and ignoring tasks. In these tasks, it seemed possible that the children possessing absolute pitch could not completely ignore the tones, in spite of the instruction. This might be because the neuronal circuit for the labeling was strongly and automatically activated in the children possessing absolute pitch. Due to their early music training, the children possessing absolute pitch were very sensitive to the tones and had tended to use their AP ability in any context. It is plausible that they executed the labeling of the tones unconsciously using their AP ability even when it was not required. Therefore, their auditory cortices were activated similarly in the single tone and ignoring tasks as in the labeling tasks. This inability to ignore the tones has been reported in the adult AP possessors [1]. In this perspective, the neuronal circuit for the AP ability might be readily activated through the automated process. In the strict sense, their attention is no longer a usual attention. Thus, the higher plasticity in the auditory cortices due to the automatic attention to the tones might be developed in this way in the children possessing absolute pitch. Of course, we cannot assert that the elicitation of the N100m was totally attributed to the activation of the neuronal circuit for labeling. But if the neuronal circuit for the labeling was activated, the N100m might well be more clearly elicited under its influence, to some extent.

There was no significant difference between the appearance rate of N100m and the possession of AP. Of course, as mentioned above, the attention levels of the children possessing absolute pitch might be higher than those of the children without absolute pitch and the appearance rate of N100m in the children possessing absolute pitch was higher than that of children without absolute pitch, there was no significant difference, however.

Some of the present subjects did not clearly exhibit the N100m. This should be interpreted with caution because MEG is largely insensitive to radial current flow. Namely, MEG cannot measure the full size of the net dipole source vector, and the lack of N100m could be due, in part, to different effective orientations of N100m dipole. The typical adult N100m elicited by auditory stimuli was, however, related to the tangential dipole source, which reflects the activity of the planum temporale and Heschl's gyrus [9–11]. In addition, multi-channel recordings of auditory evoked dipole source activities in children, aged 5–6 years old, showed that there was a tangential dipole source that composed N100m [20]. Thus, lack of N100m in the present subjects was not due to the direction of the dipole.

The lack of N100m in the present subjects was probably due to the rapid presentation of auditory stimuli; the ISI was one of the decisive factors for the appearance of the N100m. Since Sharma *et al.* [21] used 0.60 s ISI and Albrecht *et al.* [20] used < 1.0 s ISIs, N100 was not consistently elicited from early childhood. Gomes *et al.* [24] reported that, using 4.5–8 s ISIs, a clear N100 was elicited even from early childhood. About the N100m, Rojas *et al.* [25] reported that changes in the response of N100m to manipulation of ISI (2–12 s) occurred between the ages of 6 and 18 years. A clear N100m was elicited with the 4–12 s ISIs in children at 6–8 years old. They suggested that the refractory periods of N100 and N100m in children were longer than those in adults and suggested that with an ISI of < 2.0 s only a small N100m was elicited. Thus, it was natural that clear N100m was not always elicited in the condition of ISI 1.0 s, which we used in the present study.

CONCLUSIONS

We recorded N100m from the children possessing absolute pitch and reported the correlation between the age, the kinds of task, the possession of the AP and the appearance rate of N100m. Although we could not clarify the entire process of labeling in the children possessing absolute pitch, our findings seemed to reflect the strategic difference between the children possessing absolute pitch and children without absolute pitch. It was also suggested that there was an unconscious background necessary for the AP ability in this strategic difference. Further investigations on the auditory evoked magnetic fields of the children possessing absolute pitch will clarify the physiological mechanism in the children possessing absolute pitch.

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