Effects of Musical Training on the Auditory Cortex in Children

LAUREL J. TRAINOR, ANTOINE SHAHIN, AND LARRY E. ROBERTS

Department of Psychology, McMaster University, Hamilton, Ontario, Canada L8S 4K1

ABSTRACT: Several studies of the effects of musical experience on sound representations in the auditory cortex are reviewed. Auditory evoked potentials are compared in response to pure tones, violin tones, and piano tones in adult musicians versus nonmusicians as well as in 4- to 5-year-old children who have either had or not had extensive musical experience. In addition, the effects of auditory frequency discrimination training in adult nonmusicians on auditory evoked potentials are examined. It was found that the P2-evoked response is larger in both adult and child musicians than in nonmusicians and that auditory training enhances this component in nonmusician adults. The results suggest that the P2 is particularly neuroplastic and that the effects of musical experience can be seen early in development. They also suggest that although the effects of musical training on cortical representations may be greater if training begins in childhood, the adult brain is also open to change. These results are discussed with respect to potential benefits of early musical training as well as potential benefits of musical experience in aging.

KEYWORDS: auditory cortex; plasticity; learning; musical training; children; development; musicians; event-related potential (ERP)

INTRODUCTION

Recent studies have shown that the auditory cortex responds differently to sound in musicians than in nonmusicians. For example, neuromagnetic (MEG) studies have shown that the N1m response, which occurs about 100 ms after the sounding of a musical tone, is enhanced in musicians,[1] and the effect is larger for tones in the timbre of the musician's primary instrument.[2] Event-related potentials (ERPs) derived from EEG recordings have shown enhanced P2 responses at about 180 ms after sound onset and enhanced N1c responses at about 140 ms.[3] Later ERP potentials associated with the conscious interpretation of sound are also enhanced in musicians compared to nonmusicians.[4,5] These studies of functional differences between musicians and nonmusicians are paralleled by anatomic studies showing enlargement of areas important in music perception. Specifically, musicians have enlargement of the anteromedial region of Heschl's gyrus,[6] the right-sided planum,[7] and the anterior corpus callosum.[8] At the same time, nonmusicians also show remarkable

Address for correspondence: Laurel J. Trainor or Larry E. Roberts, Department of Psychology, McMaster University, Hamilton, Ontario, Canada L8S 4K1. Voice: 905-525-9140, ext. 23007; fax: 905-529-6225.
LJT@mcmaster.ca

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sensitivity to musical input. Even when they are not paying attention, ERP responses from the auditory cortex (specifically the mismatch negativity response) indicate that the brains of nonmusicians notice changes in the melodic contour (up/down pattern of pitch changes) and melodic interval (pitch distances between tones) of melodies.[9]

In this chapter, we question how these differences between musicians and nonmusicians arise. Because genetic and environmental factors interact in intricate ways from the earliest stages of development,[10] it is difficult to quantify the separate contributions of these factors. However, the question we can ask is whether the ERP components seen to be enhanced in musicians can also be enhanced through auditory training. A positive answer to this question would suggest that musical experience and practice contribute substantially to the musician/nonmusician differences seen. A second question that can be asked is how early in development differences between future musicians and nonmusicians can be seen. Recent studies indicate that auditory cortical evoked responses do not mature until late adolescence.[11,12] At the same time, there is suggestive evidence of a critical period for musical development, in that musicians who began musical training early show the largest N1m enhancement and those starting after the age of about 10 years tend not to show any N1m enlargement.[1] In the first part of this chapter, we compare musician/nonmusician cortical differences with cortical changes induced by auditory training in nonmusician adults. In the second part of this chapter, we present data comparing the cortical responses of young children with extensive musical experience to those of young children without extensive musical experience. In the final part of the chapter, we consider the implications of these findings for musical education.

PLASTICITY OF EVOKED RESPONSES: LABORATORY TRAINING IN COMPARISON WITH NATURALISTIC MUSICAL TRAINING

In Western society, people differ greatly in the amount of musical training and practice they have. This provides the grounds for a naturalistic experiment comparing nonmusicians with minimal musical experience to musicians who have had years of experience practicing for hours virtually every day. Shahin *et al*.[3] compared 11 professional violinists who were members of Canada's National Academy Orchestra, 9 pianists who had at least Grade 10 certification from Canada's Royal Conservatory of Music, and 14 university students who did not play an instrument and had no formal musical training. EEG was recorded in each participant as they listened to violin, piano, and sine wave tones (A3 and C3, American notation) matched in loudness (500-ms tones; SOA = 3,000 ms). EEG traces for all 28 channels of recorded activity distributed across the scalp are shown in FIGURE 1A for the musical tones. The dipolar patterns, where the electrical activity recorded at some sites is positive and at some sites is negative, indicate significant brain events. Clear N1b, N1c, and P2 events can be seen. Furthermore, source localization analyses using BESA software locate the generators of the activation to secondary auditory cortical areas in the temporal lobe (FIG. 1), with the P2 event located consistently more medial than the other components and the N1b more medial than the N1c.

The most interesting aspect of Shahin *et al*.[3] in the present context is that both the N1c and the P2 components were significantly larger in the musician groups than in

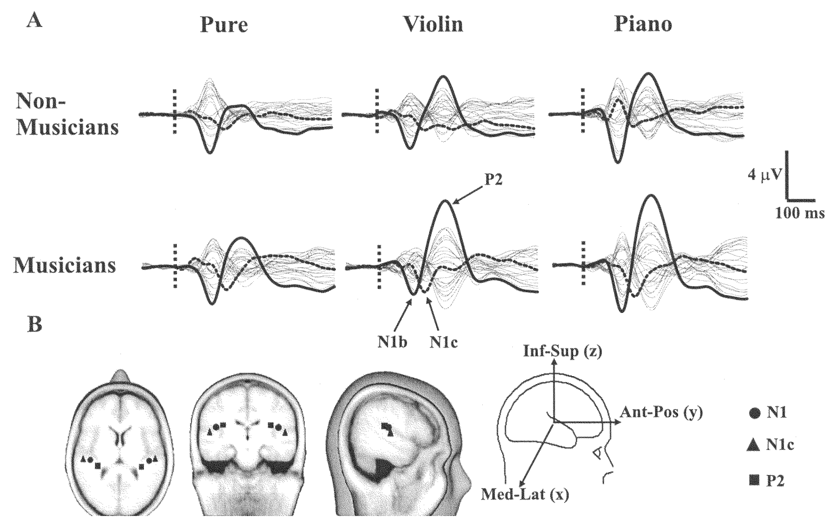

FIGURE 1. (***Upper Panel***) EEG traces for all 28 channels evoked by the sine wave, violin, and piano tones for musicians and nonmusicians. The *dashed vertical line* indicates onset of the tones. The Cz electrode is shown in *bold*, and the T8 electrode is a *dashed line*. (***Lower Panel)*** The locations of the regional sources for grand average data with a hemispheric symmetry constraint for the N1b, N1c, and P2 components determined by BESA and superimposed on the average brain of BESA.

the nonmusicians. This suggests that these brain events are critical for musical processing. However, it does not tell us if musicians were simply born with brains that give good N1c and P2 responses or if the years of musical training contributed to the observed enhancement. To examine the role of experience, the degree to which these components are neuroplastic needs to be addressed. The most stringent test of such neuroplasticity would be to train nonmusician adults, who are well beyond any critical period for musical training if one exists, in a task such as pitch discrimination and examine whether this auditory experience enhances their N1c and P2 responses. This is exactly what was done by Bosnyak *et al.*[13]

Bosnyak *et al.*[13] presented nonmusicians with sine wave tones around 2.0 kHz, amplitude modulated at 40 Hz. Initially, ERPs were measured in response to 1.8-, 2.0-, and 2.2-kHz tones. Participants were then given half an hour of training per day for 15 days in discriminating small frequency changes from the 2.0-kHz tone only. Their ERPs were then measured again at the end of training for tones at all three frequencies, and behavioral discrimination without EEG again 7 weeks later. Amplitude modulation allowed observation of the steady-state response which, because of its 40-Hz rate of modulation, is related to the middle latency responses (occurring 25 ms after stimulus onset) known to be generated in the primary auditory cortex. Interestingly, although training appeared to have no effect on the amplitude of the steady-state response (but did affect temporal properties of the steady-state response), it did have a substantial effect on the N1c and P2 components, suggesting that, in adults at least, the secondary auditory cortex is more plastic than the primary auditory cortex.

Behaviorally, the participants' ability to discriminate fine frequency differences improved for all three frequencies, but improved more for the trained 2.0-kHz tones than for the other two. Electrophysiologically, both the N1c and the P2 were larger after training, with the largest effects seen for the trained frequency of 2.0 kHz.

This training study corroborates the naturalistic musical experience study just described[3] in that the components found to be enhanced in musicians than nonmusicians were the same components found to be enhanced after frequency discrimination training. There are also two other reports that P2 amplitude increases with training. Tremblay *et al.*[14] found increased P2 amplitude after auditory temporal training, and Atienza *et al.*[15] found increased P2 amplitude after training in pitch deviance detection.

Little is yet known about what particular process the P2 brain event represents. However, a positive surface potential such as that found in the P2 is likely associated with the depolarization of pyramidal cell bodies (a sink) in deeper cortical layers (IV–VI), whereas a negative potential such as the N1b is likely to be associated with current sinks occurring on apical dendrites in the superficial layers (II–III). The observed neuroplastic changes, then, are likely to be associated with synaptic changes affecting depolarization of neurons. One possibility for the learning mechanism involves projections from the basal forebrain, which appear to modulate synaptic activity in the auditory cortex (see Shahin *et al.*[3] and Bosnyak *et al.*[13] for a discussion). In any case, the training study in conjunction with the study comparing musicians and nonmusicians suggests that learning and experience play a large role in sculpting the musical brain. In the next section, we consider how early such effects can be seen.

EARLY DEVELOPMENT OF ENHANCED RESPONSES: EVOKED POTENTIALS IN YOUNG SUZUKI MUSIC STUDENTS

Recent studies have made it clear that the auditory cortex undergoes a very protracted maturational process in normal development.[11,12] Data from our laboratory, presented in FIGURE 2, agree with these findings. In response to a violin tone, young children show a prominent P1 component, but an adult-like N1b is not seen until well into adolescence. These results suggest that the maturational level of the auditory cortex can be assessed by examining the N1b component.

Shahin *et al.*[16] asked how early in development the effects of musical experience could be seen. Would children exposed to music from an early age show more rapid development in the auditory cortex? Could this be seen in children younger than 6 years of age? To this end, Shahin *et al.*[16] compared seven 4-year-old children taking Suzuki music lessons (6 pianists and 1 violinist) with six age-matched control children who were not studying music. Parents of all the Suzuki music students reported that their children listened to a substantial amount of music in the home, and six of the seven children were in a family where at least one parent or sibling played a musical instrument and practiced at home. For the control children, only one child had a parent who played a musical instrument, and this person never practiced at home.

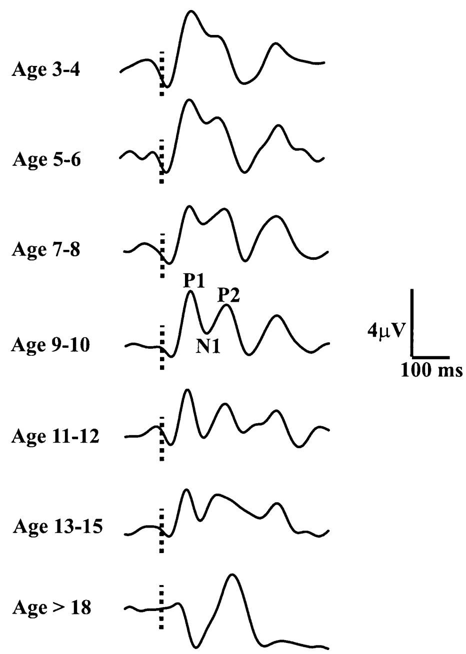

FIGURE 2. Evoked responses of children between 4 years and adulthood to a violin tone measured at a frontocentral site (Fz). The P1 component diminishes with increasing age, whereas the N1b component increases with increasing age. The number of children in each group is as follows: 10, 3–4 years; 11, 5–6 years; 14, 7–8 years; 7, 9–10 years; 10, 11–12 years; 6, 13–15 years; 14, over 18 years.

The children were presented with the same violin, piano, and sine wave tones and the same SOA (3000 ms) used in the Shahin *et al.*[3] study just discussed. Their ERPs were measured twice, once at 4 years of age, when the Suzuki music students were just starting music lessons, and once a year later when they were 5 years of age. There were no significant differences across the two measurements, so the waveforms are shown collapsed across this factor for the pure tones, violin tones, and piano tones in FIGURE 3. However, significant differences were noted between the two groups of children and between the type of tone presented.

Interestingly, ERP responses to piano tones were the most mature, in that clear P1, N1b, and P2 components could be identified, and those responses to the pure tones were least mature, in that only clear P1 components were present. The differences between the sine tones and the musical tones might reflect the increased cortical response to broad-band signals, and the differences between the violin and piano tones might reflect the more abrupt onset of the piano tones, which could be expected to generate more synchronous activation in the auditory cortex and thus lead to larger peaks in the components of the evoked potentials. Interestingly, studies of the maturation of auditory evoked potentials[11,12] showing no N1b response in

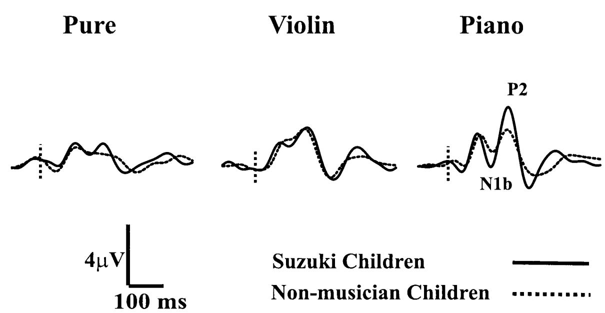

FIGURE 3. Responses of Suzuki-trained and control children to sine tones, violin tones, and piano tones from a central site on the scalp (Cz). *Dashed vertical line* indicates the onset of tones.

children of this age used much shorter SOAs (600 ms or less compared to our 3,000 ms).

Of most interest in the present context are the differences between the two groups of children. The P2 response is most clearly seen at the central vertex electrode. As can be seen in FIGURE 3, this response is also larger in the Suzuki-trained than in the control children for the piano tones. The beginnings of an N1b response can also be seen in response to the piano tones, and again FIGURE 3 shows that this response is larger in the Suzuki-trained than in the control children. It is interesting that the Suzuki-trained and the control children only differ in their responses to piano tones, because six of the seven Suzuki pupils were studying piano.

Thus, by age 4–5 years, we can differentiate two groups of children who have had different musical experiences on the basis of their auditory evoked responses. First, the N1b component appears to emerge earlier in the Suzuki group than in the control group, suggesting that this component might serve as an index of auditory cortical maturation. Second, the P2 component, which we found to differentiate musicians and nonmusicians[3] and to be enhanced with auditory training in nonmusician adults,[13] was also larger in the Suzuki-trained children than in the control children for tones of their instrument of practice. This adds to the hypothesis that this component is particularly neuroplastic.

We have shown that auditory ERPs can differentiate young children with more from those with less musical experience. However, they do not tell us if these differences are largely controlled by genetic factors or if they are largely the result of musical training. However, the fact that the same component, P2, is implicated in adult musician/nonmusician differences, is affected by auditory training in nonmusician adults, and also differentiates young children with or without extensive musical experience, suggests that experience plays a significant role in the differences seen between Suzuki-trained and control children. However, a definitive answer to this question must await studies with younger children and studies in which musical experience is explicitly controlled in the experimental design.

CONCLUSIONS AND IMPLICATIONS FOR MUSICAL TRAINING

We conclude that cortical sound representation is affected by auditory experience. Auditory training in adult nonmusicians leads to enhancement of the P2 auditory evoked potential. This same potential is enhanced in adult musicians compared with nonmusicians and is enhanced in children as young as 4 years of age who have had extensive musical experience in comparison with children who have not. Although more work is needed to clarify the role of specific experience in this enhancement, the data suggest that early musical training has a substantial effect on auditory cortical representations.

The tentative implications of this work for musical education, then, are that musical training will have a substantial effect on auditory cortical development. The optimal age for commencement of musical training remains unclear, however. Pantev *et al.*[1] found a significant correlation between the age of onset of music lessons and the size of the N1b response in musicians, with those starting lessons after age 10 not showing the effect. Trainor *et al.*[4] showed a similar correlation between the age of onset of music lessons and the size of a later component, the P3. Thus, earlier training appears to lead to larger changes in the auditory cortex. However, the relation between cortical responses and behavior is complex. The musicians in Pantev *et al.*'s study and in Trainor *et al.*'s study who commenced musical training later were not inferior musicians by behavioral standards. Thus, it is possible that early training is not essential for becoming a highly skilled musician, but that it is helpful and that those who start training later may solve the problem in a different way because they may have less plasticity in the auditory cortex.

The effects of musical training on the auditory cortex are also of interest with respect to the relation between musical training and domains other than music. For example, learning to read a language such as English involves auditory processing because in order to learn to read, children must be able to break a word into its component phonemes (e.g., "cat" is composed of three phonemes, /c/, /a/, /t/) and associate each with a written symbol. Indeed, there are reports that preschool children's phonemic awareness and early reading skill are correlated with their musical training.[17,18] In conjunction with our findings of earlier maturation of evoked responses in children with extensive musical training, these studies suggest that early musical training may enhance language and reading skills as well as musical skills. Again, however, cause-and-effect studies have not yet been done.

We conclude that auditory evoked responses can differentiate children with extensive musical training from those without it at ages as young as 4 to 5 years. In particular, the N1b and P2 components appear to emerge earlier in children with musical training. The nature of the sound appears to have a great effect on children's evoked potentials, with children of this age only showing clear components to meaningful sounds rich in harmonics and with abrupt onsets (i.e., piano tones). Interestingly, the effects of experience are not limited to children. Even adult nonmusicians given auditory training showed enhancement of the same cortical components seen to be enlarged in adult musicians and children with extensive musical experience. These results imply that musical training in adulthood and even in old age may confer benefit. Indeed, it is possible that continued musical practice may help ameliorate the effects of aging.

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