Neural Correlates of Rapid Spectrotemporal Processing in Musicians and Nonmusicians

N. GAAB,[a,b] P. TALLAL,[c] H. KIM,[a] K. LAKSHMINARAYANAN,[c]
J. J. ARCHIE,[a] G. H. GLOVER,[b] AND J. D. E. GABRIELI[a]

[a]*Department of Psychology, Stanford University, Stanford, California, USA*

[b]*Department of Radiology, Stanford University, Stanford, California, USA*

[c]*Center for Molecular and Behavioral Neuroscience, Rutgers University, Newark, New Jersey, USA*

ABSTRACT: Our results suggest that musical training alters the functional anatomy of rapid spectrotemporal processing, resulting in improved behavioral performance along with a more efficient functional network primarily involving traditional language regions. This finding may have important implications for improving language/reading skills, especially in children struggling with dyslexia.

KEYWORDS: music; language; fMRI; rapid temporal processing

INTRODUCTION

Language and reading impairments have often been characterized by phonological deficits, particularly in the ability to process rapidly presented sounds or rapid acoustic changes within sounds.[1] These findings have been accompanied by fMRI studies that show involvement mainly of left-hemispheric language and auditory areas in discrimination of speech and nonspeech stimuli characterized by rapid temporal acoustic cues.[2–4] Furthermore, musical training has been shown to improve verbal memory in adults[5] and in children,[6] as well as reading ability[7–9] and phonological segmentation.[10] Nevertheless, it remains unclear why musical training leads to improved language and reading skills.

Musical training has been shown to improve various behavioral aspects of auditory processing such as rhythm, pitch, or melody processing, and to lead to alterations of the functional brain anatomy used while performing various auditory tasks.[11] Given the link between spectrotemporal processing and language abilities, as well as between musical training and language/reading skills, we hypothesized that musical training may specifically enhance the ability to process rapid spectrotemporal acoustic cues and furthermore to alter its underlying functional anatomy. This in turn may have an influence on the acoustic/phonetic analysis skills essential to language and reading.

Address for correspondence: Nadine Gaab, Ph.D., Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room NE46-4037C, Cambridge, MA 02139. Voice: 617-253-3415.
gaab@mit.edu

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METHODS

Participants

Twenty healthy right-handed nonmusicians (NM) and 20 musicians (M) (20 women and 20 men, age range: 18–33) were recruited for this study.

Stimuli and Experimental Task

As depicted in FIGURE 1, subjects listened to three-tone sequences comprising two complex tones and were asked to reproduce the order of the tones manually. Each tone was 75 ms long and had a fundamental frequency of either 100 Hz or 300 Hz. The interstimulus interval (ISI) between the three tones varied in four steps (5 ms, 20 ms, 50 ms, and 300 ms). The sequences required either sequencing (S+: e.g., 100-300-100 Hz) or nonsequencing (S−: e.g., 100-100-100 Hz). Performance scores (% correct) and reaction times (RT) were obtained for each condition and ISI.

Imaging Procedure

The fMRI data (see FIG. 1) was collected with a 3.0T GE Signa scanner using a spiral in/out T2∗ pulse sequence with 30 slices and a sparse temporal sampling design.[12]

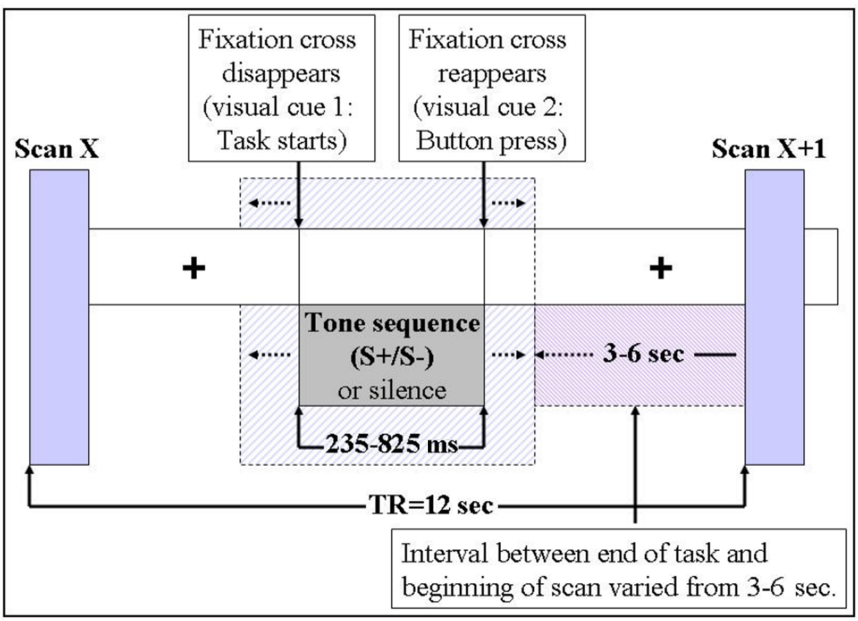

FIGURE 1. Experimental paradigm/imaging procedure.

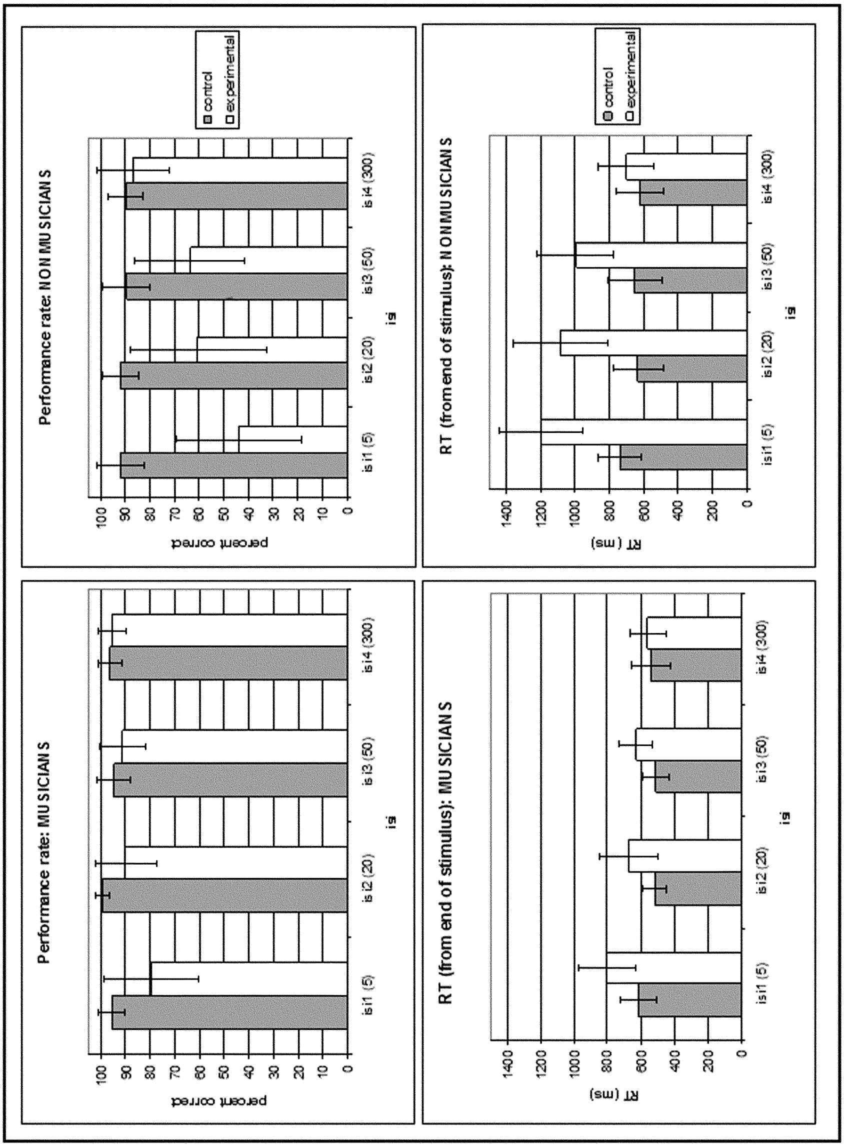

FIGURE 2. Behavioral results.

TABLE 1. Correlations in musicians' group ($P < .01^{**}$)

	Years played	Hours played last 5 years
Overall % correct (S+)	0.50**	0.45**
Overall % correct (S−)	0.41**	0.27
ISI: 5 ms (S+), % correct	0.52**	0.48**
ISI: 5 ms (S−), % correct	0.18	0.19
ISI: 300 ms (S+), % correct	0.24	0.24

fMRI Data Analysis

Following preprocessing, statistical analyses were performed using a general linear model (SPM2). A finite-impulse-response model was specified for each subject and each ISI was modeled as a separate condition. One overall (S+ versus S−) and one parametric contrast was specified for each subject. For the parametric contrast, the natural logarithm of each ISI was scaled such that four values with a mean of zero were obtained. These values were then used to test a parametric relationship (signal increase with respect to decreased ISI), and random-effect models (one- and two-sample *t* tests) were specified.

RESULTS

Behavioral Results

M showed a significantly better performance for all four ISI in S+ and for the ISIs of 20 ms and 300 ms in S−, as well as faster RTs for S+ and S− (FIG. 2). Both groups showed enhanced performance for longer versus shorter ISIs in S+. Within M, the number of years an instrument was played significantly correlated with overall performance in S+ and S− and performance in ISI 5 ms in S+. Hours played in the last 5 years significantly correlated with overall and ISI 5 ms performance in S+. No significant correlations were found for performance in ISI 5 ms in S− or ISI 300 ms in S+ (TABLE 1).

IMAGING RESULTS

The Sequencing Effect

Within the NM group, significant activations for S+ versus S− were observed in bilateral superior temporal gyrus, inferior/middle frontal gyrus, inferior parietal regions, pre/postcentral and central gyrus, the cuneus, right lingual gyrus and the anterior cingulate (see FIG. 3). Within the M group, this contrast revealed bilateral activation of the superior temporal gyrus and the left postcentral gyrus (all $P < .05$, corrected).

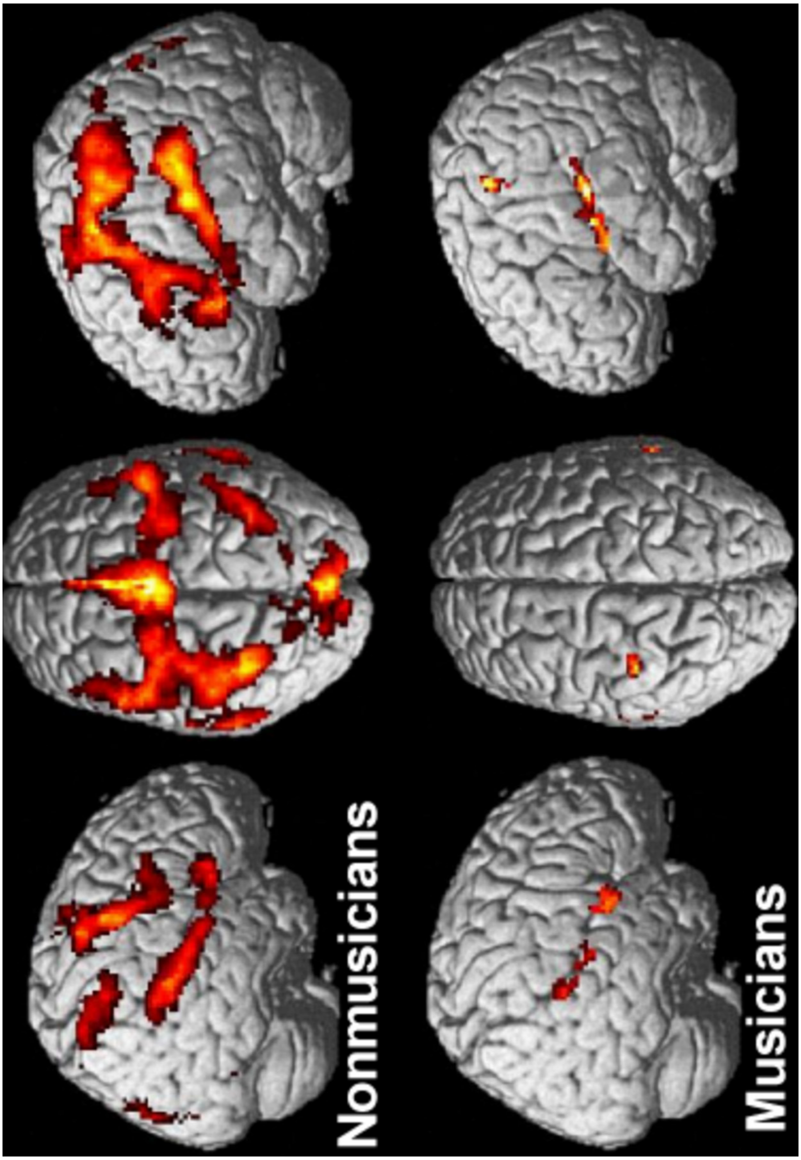

FIGURE 3. Imaging results: sequencing effect. (*See online version for color figure.*)

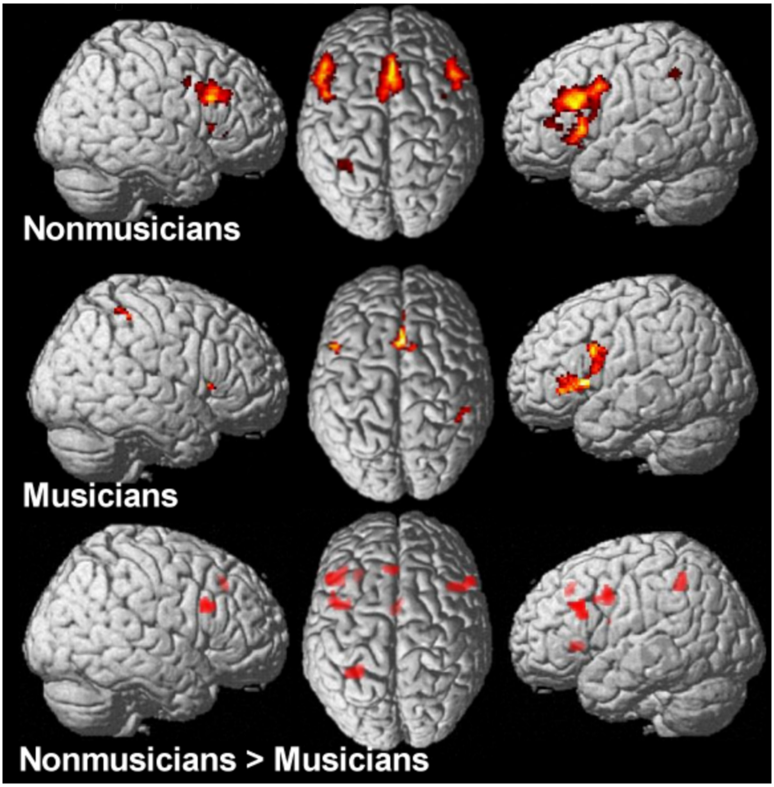

FIGURE 4. Imaging results: rapid spectrotemporal processing effect. (*See online version for color figure.*)

The Rapid Temporal Sequencing Effect

As shown in FIGURE 4, among NM, this analysis revealed activation of bilateral inferior/middle/medial frontal gyrus, the anterior cingulate, and a left inferior parietal region ($P < .001$). Among M, this analysis revealed activation of bilateral inferior frontal regions, the anterior cingulate, and a right inferior parietal region (all $P < .001$). The contrast NM > M revealed increased activation of left inferior frontal gyrus, bilateral middle frontal and left medial frontal gyrus, the anterior cingulate and a left inferior parietal region ($P < .005$).

DISCUSSION

Overall, this study suggests that musical training not only improves nonverbal rapid spectrotemporal processing, but also changes the neural network involved in rapid spectrotemporal processing so that it overlaps primarily with brain areas traditionally associated with language processing (e.g., Broca's region).

Results from previous studies indicate that acoustical training aimed to improve rapid auditory processing ability is beneficial to children struggling with language and reading.[1] Our findings further show that musical experience can improve the processing of auditory stimuli that require rapid spectrotemporal processing and therefore might enhance the acoustic/phonetic skills essential to language/reading as has been suggested by behavioral studies.[5–10]

Further studies should focus on the exact neural mechanisms underlying the relationship between nonverbal and verbal rapid spectrotemporal processing, its brain correlates (especially the role of the inferior frontal gyrus), and the potential role musical training may play in improving language and literacy skills.

[Competing interest: We have potential conflicts of interest. Paula Tallal is a cofounder and director of Scientific Learning Corporation. She is also a consultant for Posit Science Corporation and Mind Streams Corporation, and serves on their scientific advisory boards.]

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