The Effects of Musical Training on Structural Brain Development

A Longitudinal Study

Krista L. Hyde,[a] Jason Lerch,[b] Andrea Norton,[c] Marie Forgeard,[c] Ellen Winner,[d] Alan C. Evans,[a] and Gottfried Schlaug[c]

[a]*Montreal Neurological Institute, McGill University, Montreal, Quebec, Canada*

[b]*Mouse Imaging Centre, Hospital for Sick Children, Toronto, Ontario, Canada*

[c]*Department of Neurology, Music and Neuroimaging Laboratory, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, Massachusetts, USA*

[d]*Department of Psychology, Boston College, Chestnut Hill, Massachusetts, USA*

Long-term instrumental music training is an intense, multisensory and motor experience that offers an ideal opportunity to study structural brain plasticity in the developing brain in correlation with behavioral changes induced by training. Here, for the first time, we demonstrate structural brain changes after only 15 months of musical training in early childhood, which were correlated with improvements in musically relevant motor and auditory skills. These findings shed light on brain plasticity, and suggest that structural brain differences in adult experts (whether musicians or experts in other areas) are likely due to training-induced brain plasticity.

Key words: **brain plasticity; development; music; children; MRI**

Introduction

Studies comparing adult musicians with matched nonmusicians have revealed structural and functional differences in musically relevant brain regions, such as sensorimotor brain areas,[1–3] auditory areas,[4–7] and multimodal integration areas.[8–11] However, no studies have yet examined structural brain and behavioral changes in the developing brain in response to long-term music training to specifically address the question of whether structural brain differences seen in adults (comparing experts with matched controls) are a product of "nature" or "nurture."

As part of an ongoing longitudinal study of the effects of music training on brain, behavioral, and cognitive development in young children,[12,13] here we investigated structural brain changes in relation to behavioral changes in young children who received 15 months of instrumental musical training relative to a group of children who did not. We used deformation-based morphometry (DBM),[14] an unbiased and automated approach to brain morphology, to search throughout the whole brain on a voxel-wise basis for local brain size (voxel expansions or contractions) differences between groups over the 15 months.

Materials and Methods

Participants

The Instrumental group consisted of 15 children (mean age at start of study: 6.32 years old,

Addresses for correspondence: Krista L. Hyde, Montreal Neurological Institute, McGill University, 3801 University Street, Montreal, Quebec, H3A 2B4, Canada. krista.hyde@mail.mcgill.ca and Gottfried Schlaug, Department of Neurology, Music and Neuroimaging Lab, Beth Israel Deaconess Medical Center and Harvard Medical School, 330 Brookline Avenue, Boston, MA 02215. gschlaug@bidmc.harvard.edu

The Neurosciences and Music III: Disorders and Plasticity: Ann. N.Y. Acad. Sci. 1169: 182–186 (2009).
doi: 10.1111/j.1749-6632.2009.04852.x

SD 0.82 years) who received private keyboard instruction for 15 months. The Control group consisted of 16 children (mean age at start of study: 5.90 years old, SD 0.54 years) who did not receive any instrumental music training during this 15-month period, but did participate in a weekly group music class in school (i.e., singing and drums). The Instrumental and Control children were all right-handed and matched as closely as possible in gender, age at the start of the study, and socioeconomic status. At time 1, all children were tested on a series of behavioral tests, and underwent an MRI scan (scan 1). At time 2 (15 months later), all children were retested on the behavioral tests and underwent a second MRI scan (scan 2). This research was approved by the ethics committees of the Beth Israel Deaconess Medical Center.

Behavioral Tests

Children were tested individually at times 1 and 2 on two musically relevant behavioral tasks: a 4-finger motor sequencing test for the left and right hands assessing fine finger motor skills, and a custom-made "Melodic and Rhythmic Discrimination Test Battery," assessing music listening and discrimination skills. Five nonmusical tasks were also administered: the Object Assembly, Block Design, and Vocabulary subtests of the WICS-III,[15] the Raven's Progressive Matrices,[16] and the Auditory Analysis Test[17] (see Refs. 12 and 18 for details). Behavioral "difference scores" measuring the difference in performance on the behavioral tests from time 1 to time 2 were calculated and then correlated with brain deformation measures.

Brain Analyses

T1-weighted anatomic MRI scans were obtained for all children on a 3T General Electric MRI scanner. Automated deformation brain analyses were performed on the T1 MRI data for each child using MNI autoreg tools.[14] Statistical analyses were performed according to the general linear model and results were thresholded using random field theory cluster thresholding.[19]

Results and Discussion

There were no behavioral or brain differences between the Instrumental and Control children at base line (prior to any music training). These results support the view that brain differences seen in adult musicians relative to nonmusicians are more likely to be the product of intensive music training rather than biological predispositions to music.[12,13]

As predicted, Instrumental children showed greater behavioral improvements over the 15 months on the finger motor task and the melody/rhythmic tasks, but not on the nonmusical tasks. In addition, Instrumental children showed areas of greater relative voxel size change over the 15 months as compared to Controls in motor brain areas, such as the right precentral gyrus (motor hand area, Fig. 1A), and the corpus callosum (4th and 5th segment/midbody, Fig. 1B), as well as in a right primary auditory region (Heschl's gyrus, Fig. 1C). These brain deformation differences are consistent with structural brain differences found between adult musicians and nonmusicians in the precentral gyri,[2] the corpus callosum,[20–22] and auditory cortex.[2,4,23]

The brain deformation changes found between Instrumental and Control children in motor and auditory brain areas, were predicted by behavioral improvement scores on the finger-motor (Fig. 1A and B) and melody/rhythmic tasks (Fig. 1C), respectively. These results are important from a functional perspective since these brain regions are known to be of critical importance in instrumental music performance and auditory processing. For example, the primary motor area plays a critical role in motor planning, execution, and control of bimanual sequential finger movements as well as motor learning,[24,25] and intense bimanual motor training of musicians could play

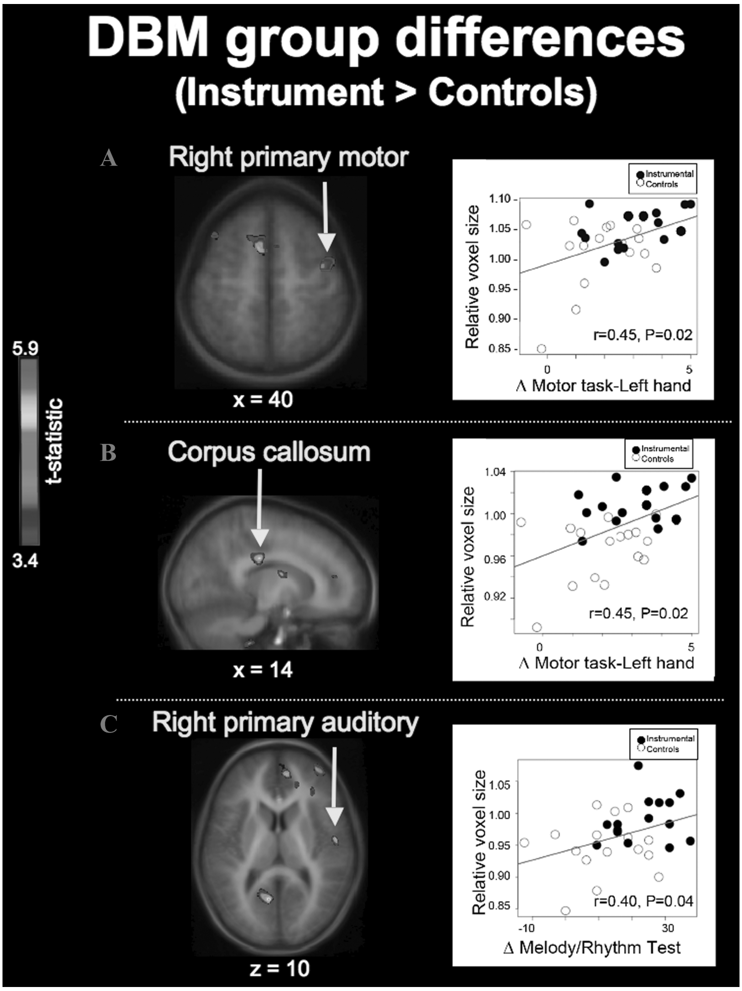

Figure 1. Group brain deformation differences. The brain images in panels **A**, **B**, and **C** show areas of significant brain deformation (DBM) differences over 15 months in Instrumental ($n = 15$) versus Control ($n = 16$) children in terms of a t-statistical color map of the significant clusters superimposed on an average MR image of all children. The significant positive correlations of relative voxel size with behavioral difference scores (from time 1 to time 2, either on the left-hand motor task or the melody/rhythmic task) for each child are plotted at the peak (most significant voxel shown by the yellow arrow) in the right primary motor area (precentral gyrus; $x = 40$, $y = -7$, $z = 57$; $t = 4.2$, $P < 0.05$ at whole-brain cluster threshold) in panel **A**, in the corpus callosum ($x = 14$, $y = -24$, $z = 30$; $t = 5.2$, $P < 0.05$ at whole-brain cluster threshold) in panel **B**, and in the right primary auditory area (Heschl's gyrus; $x = 55$, $y = -8$, $z = 10$; $t = 4.9$, $P < 0.1$ at *a priori* cluster threshold) in panel **C**. A relative voxel size of 1 indicates no brain deformation change from time 1 and values greater than 1 indicate voxel expansion, whereas values less than 1 indicate voxel contraction. For example, a value of 1.1 at voxel X indicates a 10% expansion from time 1, whereas 0.9 indicates a 10% contraction. (In color in *Annals* online.)

an important role in the determination of callosal fiber composition and size.[21] The correlation found between the brain deformation measures and the melody/rhythmic test battery in the right primary auditory region is consistent with functional brain mapping studies that have found activity changes using auditory-musical tests in similar auditory regions.[26]

While structural brain differences were expected in motor and auditory brain areas, unexpected significant brain deformation differences were also found in various frontal areas, the left posterior peri-cingulate, and a left middle occipital region. However, none of these unexpected deformation changes were correlated with motor or auditory test performance changes. These findings indicate that plasticity can occur in brain regions that control primary functions important for playing a musical instrument, and also in brain regions that might be responsible for the kind of multimodal sensorimotor integration likely to underlie instrumental learning.

These results provide new evidence for training-induced structural brain plasticity in early childhood. These findings of structural plasticity in the young brain suggest that long-term intervention programs can facilitate neuroplasticity in children. Such an intervention could be of particular relevance to children with developmental disorders and to adults with neurologic diseases.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Elbert, T. *et al*. 1995. Increased cortical representation of the fingers of the left hand in string players. *Science* **270:** 305–307.
2. Gaser, C. & G. Schlaug. 2003. Gray matter differences between musicians and nonmusicians. *Ann. N. Y. Acad. Sci.* **999:** 514–517.
3. Hund-Georgiadis, M. & D.Y. von Cramon. 1999. Motor-learning-related changes in piano players and non-musicians revealed by functional magnetic-resonance signals. *Exp. Brain Res.* **125:** 417–425.
4. Bermudez, P. & R.J. Zatorre. 2005. Differences in gray matter between musicians and nonmusicians. *Ann. N. Y. Acad. Sci.* **1060:** 395–399.
5. Lappe, C. *et al*. 2008. Cortical plasticity induced by short-term unimodal and multimodal musical training. *J. Neurosci.* **28:** 9632–9639.
6. Pantev, C. *et al*. 1998. Increased auditory cortical representation in musicians. *Nature* **392:** 811–814.
7. Zatorre, R.J. 1998. Functional specialization of human auditory cortex for musical processing. *Brain* **121**(Pt 10): 1817–1818.
8. Bangert, M. & G. Schlaug. 2006. Specialization of the specialized in features of external human brain morphology. *Eur. J. Neurosci.* **24:** 1832–1834.
9. Gaser, C. & G. Schlaug. 2003. Brain structures differ between musicians and non-musicians. *J. Neurosci.* **23:** 9240–9245.
10. Sluming, V. *et al*. 2007. Broca's area supports enhanced visuospatial cognition in orchestral musicians. *J. Neurosci.* **27:** 3799–3806.
11. Zatorre, R.J., J.L. Chen & V.B. Penhune. 2007. When the brain plays music: auditory-motor interactions in music perception and production. *Nat. Rev. Neurosci.* **8:** 547–558.
12. Norton, A. *et al*. 2005. Are there pre-existing neural, cognitive, or motoric markers for musical ability? *Brain Cogn.* **59:** 124–134.
13. Schlaug, G. *et al*. 2005. Effects of music training on the child's brain and cognitive development. *Ann. N. Y. Acad. Sci.* **1060:** 219–230.
14. Collins, D.L. *et al*. 1994. Automatic 3D intersubject registration of MR volumetric data in standardized Talairach space. *J. Comput. Assist. Tomogr.* **18:** 192–205.
15. Wechsler, D. 1991. *WISC-III Wechsler Intelligence Scale for Children*, third edition: Manual. The Psychological Corporation. San Antonio, TX.
16. Raven, J. 1976. *Coloured Progressive Matrices*. Oxford Psychologists. Oxford, UK.
17. Rosner, J. 1971. Test of auditory analysis skill, TAAS. *J. Learn. Disabil.* **4:** 40–48.
18. Forgeard, M. *et al*. 2008. Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *PLoS ONE* **3:** e3566.
19. Genovese, C.R., N.A. Lazar & T. Nichols. 2002. Thresholding of statistical maps in functional neuroimaging using the false discovery rate. *NeuroImage* **15:** 870–878.
20. Lee, D.J., Y. Chen & G. Schlaug. 2003. Corpus callosum: musician and gender effects. *Neuroreport* **14:** 205–209.
21. Schlaug, G. *et al*. 1995. Increased corpus callosum size in musicians. *Neuropsychologia* **33:** 1047–1055.
22. Schmithorst, V.J. & M. Wilke. 2002. Differences in white matter architecture between musicians and non-musicians: a diffusion tensor imaging study. *Neurosci. Lett.* **321:** 57–60.
23. Schneider, P. *et al*. 2002. Morphology of Heschl's gyrus reflects enhanced activation in the auditory cortex of musicians. *Nat. Neurosci.* **5:** 688–694.

24. Grodd, W. *et al*. 2001. Sensorimotor mapping of the human cerebellum: fMRI evidence of somatotopic organization. *Hum. Brain Mapp.* **13:** 55–73.
25. Karni, A. *et al*. 1995. Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature* **377:** 155–158.
26. Zatorre, R.J., P. Belin & V.B. Penhune. 2002. Structure and function of auditory cortex: music and speech. *Trends Cogn. Sci.* **6:** 37–46.