

Training-induced Neuroplasticity in Young Children

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As the main interhemispheric fiber tract, the corpus callosum (CC) is of particular importance for musicians who simultaneously engage parts of both hemispheres to process and play music. Professional musicians who began music training before the age of 7 years have larger anterior CC areas than do nonmusicians, which suggests that plasticity due to music training may occur in the CC during early childhood. However, no study has yet demonstrated that the increased CC area found in musicians is due to music training rather than to preexisting differences. We tested the hypothesis that approximately 29 months of instrumental music training would cause a significant increase in the size of particular subareas of the CC known to have fibers that connect motor-related areas of both hemispheres. On the basis of total weekly practice time, a sample of 31 children aged 5–7 was divided into three groups: high-practicing, low-practicing, and controls. No CC size differences were seen at base line, but differences emerged after an average of 29 months of observation in the high-practicing group in the anterior midbody of the CC (which connects premotor and supplementary motor areas of the two hemispheres). Total weekly music exposure predicted degree of change in this subregion of the CC as well as improvement on a motor-sequencing task. Our results show that it is intense musical experience/practice, not preexisting differences, that is responsible for the larger anterior CC area found in professional adult musicians.

Key words: music; brain; corpus callosum; children; plasticity

Introduction

Can practicing a complex task for 2 h a week influence the development of children's brains? The effect of experience on brain structure has already been demonstrated in non-human animals, as well as in human adults learning to juggle over 3 months.¹ We investigated the possibility that the environmentally induced demands of instrumental music training in childhood alter the development of interhemispheric connections through the cor-

pus callosum (CC). Learning to play a musical instrument involves complex cognitive and bimanual motor skill acquisition as well as sensory stimulation and this experience provides an ideal activity with which to investigate changes in the brain as a function of learning. As the main interhemispheric fiber tract, the CC is of particular importance for musicians, who simultaneously engage areas of both hemispheres to perform coordinated but also independent movements with two hands. Indeed, adult professional musicians have been shown to have larger CCs than do nonmusicians,^{2,3} and intensity of instrumental practice in childhood correlates positively with differences in callosal fractional anisotropy in musicians versus nonmusicians.⁴ However, since

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these studies could not rule out the possibility of CC differences existing prior to training (e.g., genetically determined differences), we used a longitudinal design to test the causal claim that the environmental demands of music training can alter the structure of the developing CC.

Method

Thirty-one children (mean age = 6.49 years) participated. Eighteen children attended weekly half-hour private or semi-private instrumental lessons (11 children learned the piano; seven learned string instruments), while 13 children served as noninstrumental controls and received no instrumental training. The “instrumental children” were classified as low practicers ($n = 12$; range: 1–2 h/week) or high practicers ($n = 6$; range: 2–5 h/week). All children underwent high-resolution T1-weighted MR brain scans (voxel size: $0.93 \times 0.93 \times 1.5$ mm) both at base line and after a mean of almost 30 months of music training. The total midsagittal callosal area and seven midsagittal subareas were determined by a blind observer. The anatomic subdivision into the callosal subareas 1–7 corresponds to that originally described by Witelson.⁵ Data analysis was restricted to areas 3–6, the four areas that could plausibly be affected by instrumental music training since they contain fibers projecting to sensory and motor cortical regions.⁶ Areas 1, 2, and 7 were excluded from analysis because effects found in these areas would be unlikely to be due to instrumental training. For details on CC measurements and delineations,^{2,3} see Figure 1A. Total CC size as well as subareas were measured and corrected for total brain volume. The anterior midbody of the CC contains traversing fibers from prefrontal cortex, premotor region, and supplementary motor areas⁶ (Fig. 1B). Children also completed a 4-finger fine motorskill sequencing task^{7,8} at both time points. Beginning with their nondominant hand, children performed three 30-s trials of a 4-finger sequence

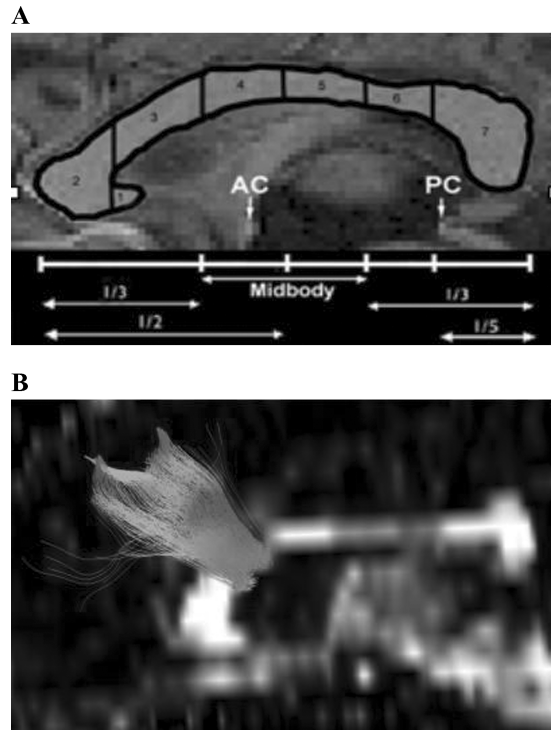


Figure 1. (A) Subdivisions of the midsagittal CC (see location of area 3 on the midsagittal slice). AC = anterior commissure; PC = posterior commissure. (B) Diffusion tensor imaging showing fibers traversing through area 3 of the midsagittal CC to connect bilateral prefrontal, premotor, and supplementary motor regions. (In color in *Annals* online.)

task on the number keys of an alpha-numeric computer keyboard with each hand, with a 30-s rest period between trials. Full credit (a score of 1) was given for each correct 5-key press sequence; partial credit was given for sequences with four consecutive and three consecutive key presses (score of 0.8 and 0.6, respectively). Scores from the three trials were averaged for each hand.

Results

Instrumental music training significantly ($P = 0.02$) affected the development of the middle third of the anterior body of the CC (area 3) (Fig. 2). Preliminary ANOVAs showed

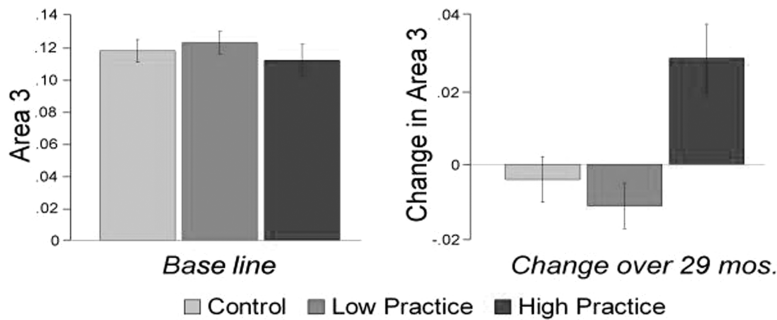


Figure 2. Proportional size of area 3 at base line and absolute change in area 3 of the midsagittal CC (corrected for total brain volume) over 29 months, by group. (In color in *Annals* online.)

that groups did not differ in gender or interval months between their first and second scans (all $P > 0.1$). However, groups did differ in age ($P < 0.05$): high and low practicers were somewhat older than controls at the beginning of the study. An ANCOVA (covarying age) also confirmed that groups did not differ in size of area 3 at base line ($P > 0.1$). Four ANCOVAs (covarying age) were conducted in order to determine whether groups differed in absolute change in areas 3–6 of the CC. The family-wise error rate was corrected by applying a Bonferroni correction to the resulting P -values. Groups did not differ in change in areas 4–6 (all $P > 0.1$). However, a significant effect of group was found for the absolute change observed in area 3 [$F(2, 27) = 6.624, P = 0.02$]. Bonferroni post-hoc tests revealed that high practicers had a significantly larger change than did both low practicers ($P < 0.01$) and controls ($P = 0.03$). Low practicers and controls did not differ in extent of change ($P > 0.1$).

Additional multiple regressions (controlling for age, gender, and interval) revealed that practice intensity predicted change in area 3 ($P = 0.03$, partial $r^2 = 0.18$). Multiple regression also demonstrated that improvement on the motor sequencing task with the non-dominant hand significantly predicted change in area 3 ($P = 0.02$, partial $r^2 = 0.24$) (Fig. 3). Improvement with the dominant hand did not predict change in area 3 ($P > 0.1$). Practice intensity predicted improvement in motor per-

formance with both the nondominant ($P < 0.1$, partial $r^2 = 0.58$) and the dominant ($P = 0.01$, partial $r^2 = 0.25$) hands (Fig. 3).

Discussion

The predominant effect of practice intensity in one subregion of the CC should be seen in the context of recent diffusion tensor imaging studies showing that fibers traversing through area 3 of the CC project mainly to the prefrontal cortex, premotor, and supplementary motor areas.⁶ These three cortical regions all participate in motor preparation and planning and have modulating effects on motor execution. The differential effect of instrumental music training on structural development of the CC might be due to growth of myelination (axons with thicker myelin sheets), axon size, the increased formation of axon collaterals, or number of transcallosal fibers that could result from interference of bimanual activities in the pruning of interhemispheric fibers during development.^{4,9} Results of our study provide evidence that early, intensive, and prolonged skill learning leads to significant structural changes in the brain, changes that are associated with changes in related behavioral skill. Future studies should explore the mechanisms through which experience-dependent structural brain changes take place.

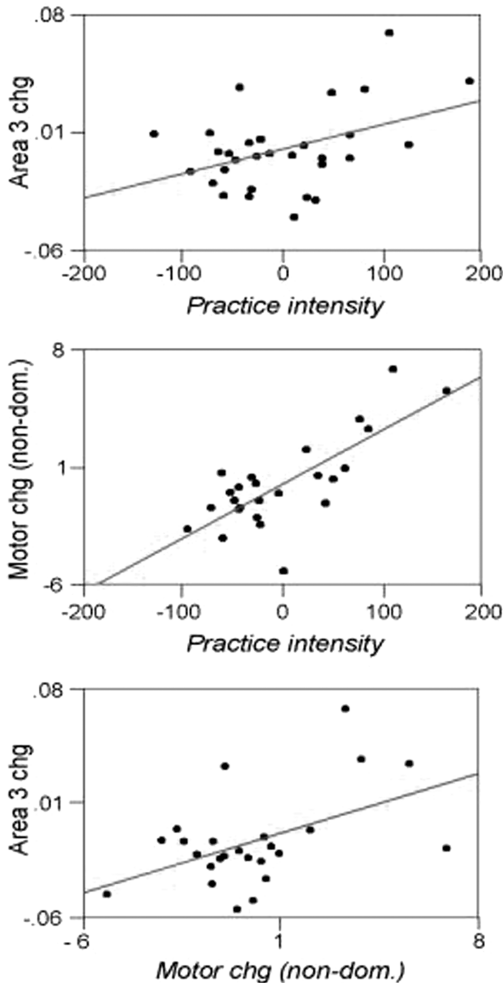


Figure 3 (Top) Practice intensity (in minutes/week) predicts absolute change in area 3 of the midsagittal CC (corrected for brain volume), controlling for age, gender, and interval between the two scanning sessions. (Middle) Practice intensity (in minutes/week) predicts absolute improvement in motor performance (using the nondominant hand), controlling for age, gender, and interval between the two scanning sessions. (Bottom) Absolute improvement in motor performance (using the nondominant hand) predicts absolute change in area 3 of the midsagittal CC (corrected for brain volume), controlling for age, gender, and interval between the two scanning sessions. (In color in *Annals* online.)

Acknowledgments

This research was supported by the National Science Foundation (Grant BCS0518837), the International Foundation for Music Research (IFMR), the Dana Foundation, and the Grammy Foundation.

Conflicts of Interest

The authors declare no conflicts of interest.

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