The Relationship Between Instrumental Music Training and Corpus Callosum Growth

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Boston College Electronic Thesis or Dissertation, 2004

The Relationship Between Instrumental Music Training and Corpus Callosum Size

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Senior Thesis, April 2004
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Abstract

Recent studies have shown differences between several structures in the brains of professional level musicians and non-musicians. Professional musicians form an ideal group to study changes in the human brain due to the unique abilities required of them. Since many musicians begin training at a young age, it is assumed that these differences are attributable to intense, early experience brought on by the cognitive and motor demands of music training. However, it remains to be seen whether these structural differences are due to changes brought on by experience or preexisting ones which draw children to music lessons. Using magnetic resonance images, I compared the size of the corpus callosums in two groups of children who ranged between the ages of five and seven, one just beginning music lessons and another not beginning music lessons. I also compared the groups in terms of their performance on a finger tapping test for differences in speed and accuracy. A second set of comparisons of callosal size was conducted between nine-to-eleven year-olds who had been taking music lessons for at least a year and those who had not. Differences in the five-to-seven-year-olds were seen in the anterior corpus callosum corrected for brain volume between the musician and non-musician groups. Differences in accuracy of finger tapping were seen between the musicians and non musicians, as well as between those in the musician group who had received less than sixteen or twenty-five weeks of training versus those who had received less. These findings indicate that while musicians start out with at least one slightly larger measure of corpus callosum size, differences in finger skill tend to develop slowly.

Introduction

Professional level musicians exhibit cognitive and motor abilities tailored to the unusual performance demands placed upon them. Aside from being able to memorize lengthy musical phrases, musicians must monitor auditory sequences for accuracy in both timing and pitch. Ensemble performance mandates synchronized execution of certain notes, and orchestral musicians, in particular, rely on the audiospatial localization of tones to take cues from other sections. Both these abilities require an extremely precise window of temporal integration for sounds. Detection of error in melody necessitates heightened sensitivity to differences in pitch; and certain musicians are able to identify tones in the absence of a reference note, an ability known as absolute pitch. In addition, musicians must learn to translate visual symbols with specific spatial relationships into motor outputs in order to sight-read. Playing an instrument also requires complex bimanual hand and finger movements demanding heightened dexterity in both the dominant and non-dominant hands. Unique challenges arise whether these sequences require precise functional coordination of both hands, in the case of string players, or detailed, independent performance, as is typical in keyboardists.

Evidence that Brains of Adult Musicians are Atypical

The brains of adult musicians are larger in certain areas than are the brains of non-musicians. These differences may be a result of the intense cognitive and behavioral demands of playing an instrument, especially given that most musicians begin playing their instrument at a young age, when the brain is still highly plastic. The following differences in musicians' brains compared to those of non-musicians have been demonstrated through anatomical magnetic resonance imaging (MRI) studies:

Planum temporale. Absolute pitch musicians have a stronger leftward bias in the planum temporale than do both musicians without absolute pitch as well as non-musicians. This stronger leftward bias is due to absolute pitch musicians having a smaller right planum temporale (Schlaug, 1995; Keenan, 2001).

Cerebellum. The cerebellum is involved in motor skill acquisition and performance through error feedback. Right-handed male musicians have a larger cerebellum relative to total brain size than do non-musicians. Relative cerebellar size also correlated positively with duration and intensity of training and practice, as well as an early age of commencement (Hutchinson, 2001).

Primary motor cortex. The intrasulcal length of the precentral gyrus, a measure of the primary motor cortex, showed a decreased right asymmetry in right handed male musicians compared to controls due to a larger right intrasulcal length in the musicians group. There was also a negative correlation between age at commencement of training and the size of both the right and left intrasulcal length (Amunts, 1997).

Gray matter. Increased gray matter has been found in various areas in musicians compared to non-musicians. Amateur musicians have more gray matter in the premotor area, a region associated with bimanual finger movements, than do non-musicians, and professional musicians have more gray matter in this area than do amateurs (Gaser, 2003).

The superior parietal area showed similar increases in gray matter volume with increasing degrees of musicianship. This area is known to play a key role in visuomotor integration during activities such as reaching and grasping, and could provide guidance for motor operations through its connections with the premotor cortex, making it a likely substrate for the skills underlying sight-reading (Stewart, 2003; Gaser, 2003).

A positive correlation between gray matter volume and musicianship was also found in the left inferior frontal gyrus in the Broca's region of orchestral musicians. Broca's region is commonly associated with speech production. However, many of the requirements for music, such as monitoring and adjusting motor function based on analysis of auditory sequences, are similar to those required by speech, as indicated by the above structural evidence (Sluming, 2002).

White matter. Similar studies have identified differences in white matter distribution between musicians and non-musicians. Schmithorst and Wilke (2002) found that musicians display increases in white matter in the cerebellum and anterior corpus callosum and decreases in white matter in the corona radiate compared to controls. Although increases in white matter in the corona radiata are typically considered normal in the development of fine motor skills, the authors reconcile this contradiction by hypothesizing that areas such as the striatum and cerebellum, which shows white matter increases, take over the ordinary functions of the corona radiata to conserve working memory since they specialize in repetitive movements and long term retention.

A significant amount of white and gray matter configuration takes place in early childhood and adolescence, much like the course of growth of the corpus callosum discussed below. Between ages 6 and 18, there is an overall reduction in gray matter volume and increase in both white matter volume and corpus callosum size, with the changes being particularly pronounced in males (De Bellis, 2001). Since this period coincides with normal development of finger skills and the usual commencement of music training, it is possible that the cognitive and motor demands of music training play a significant role in determining the course of development of these factors.

The Corpus Callosum and its Involvement in Musicianship:

The corpus callosum, the main tract of interhemispheric axonal fibers in the brain, plays a key role in the communication and integration of information between the two hemispheres of the brain. Schlaug (1995) demonstrated that the anterior corpus callosum was significantly larger in adultmusicians than in adultnon- musicians and that the difference was attributable to the subgroup of musicians who began training before age seven. Differences in callosal size are typically indicative of differences in interhemispheric connectivity, as demonstrated by Steinmetz (1992), who found larger callosal isthmus area in women, who are considered to have less asymmetrically organized brains than men.

Increased interhemispheric communication is necessary for musical performance for a number of reasons. The left and right primary sensorimotor areas have demonstrated increasingly symmetrical EEG activations in correlation with the size of the corpus callosum following unimanual finger and shoulder movements (Stancak, 2002). This finding was interpreted as evidence that a large callosal body promotes synchronization of cortical activity over corresponding areas in both hemispheres. This heightened bilateral functional coupling resulting from increased corpus callosum size could facilitate coordination of complex finger sequences performed by musicians. Similarly, correlations have been found between the size of the corpus callosum and the extent of activation of the supplementary motor area, cingulate cortex, primary motor and premotor areas, prefrontal cortex, and temporal cortex during bimanual finger movements (Stancak, 2003). Simultaneous activation of the supplementary motor areas, in particular, is prompted by callosal connections and is necessary for temporal coordination of bimanual movements. Monkeys with unilateral lesions of the supplementary motor area, will produce parallel movements of both hands when given electrical stimulation to the intact area, presumably due to the density of callosal fibers connecting the two hemispheres.

The possible role of the corpus callosum in the visuomotor integration necessary for sight reading is evidenced by the Poffenberger paradigm as described by Berlucchi (1995). In this example, the reaction time to a brief flash of light in one hemifield, which is projected to the contralateral hemisphere, is shorter with the hand ipsilateral to the stimulus than for responses with the other hand. Since motor neurons for hand movement, particularly distal finger movements which require no global action or modification of posture, originate in the contralateral hemisphere, responses with the hand ipsilateral to the stimulus must cross the corpus callosum while contralateral responses remain uncrossed. The difference in reaction time is regarded as a measure of interhemispheric transfer speed. Subjects with callosal deficits such as agenesis or partial commisurotomy show increased transfer times since the information must travel along less direct pathways.

Studies have also implicated increased corpus callosum size as a measure of decreased laterality in the brain, a characteristic trait of professional musicians. Yazgan et al. (1995) found that increasing callosal area led to a decreased right ear advantage on a dichotic listening test in right-handed subjects. Because most right-handers demonstrate a left hemisphere specialization for language, it was assumed that a larger corpus callosum size would activate the less verbally-specialized right hemisphere and impede the dominant hemisphere for the task. Similar insight into the neurophysiological function of the corpus callosum comes from findings showing that musicians exhibit reduced interhemispheric inhibition on transcranial magnetic stimulation tests. Ridding (2000) found that transcranial magnetic stimulation applied to the hand area of the motor cortex of one hemisphere is less effective at reducing the size of responses evoked by transcranial magnetic stimulation applied to the same region in the opposite hemisphere in professional musician compared to controls. It has been suggested by Ridding that the functional adaptation of inhibition of the opposite motor cortex via the corpus callosum may assist in the performance of symmetrical and asymmetrical bimanual movements and in the suppression of movement with the opposite hand during unimanual tasks.

The corpus callosum has been shown to exhibit a strong, linear growth between ages 4 and 18, a period in which finely tuned finger movements reach their adult levels. Corpus callosum size is determined by the number of axons composing the tract and the degree of myelination of these neurons. Since new axons do not develop postnatally, this increase is most likely due to age-related increase in myelination. These structural increases are among the most noticeable in the brain, as the corpus callosum is the last neuronal tract to complete myelination and has been shown to continue development into the third decade of life (Geidd, 1996).

The finding of rapid increases in corpus callosum size during early childhood complements other studies in establishing that the corpus callosum plays an essential role in the execution of bimanual motor movements (which are of course essential in playing an instrument). In a test in which children were asked to draw lines of varying angles on a computer screen using two knobs controlling either the vertical or horizontal progress of the line, trials requiring the use of only one hand showed a direct correlation between speed and age with a stronger correlation in the left hand. Angles requiring identical speed in both hands, a measure of simple visuomotor coordination, showed a correlation between age and accuracy, but not speed of completion when controlled for unimanual speed. The strongest correlations between age and accuracy were found on angles which demanded greater speed in the left hand, even after controlling for visuomotor coordination, with the bulk of the deviation resulting from excess speed of the right hand (Marion, 2003). Because bimanual performance in younger children typically mirrors that of acallosal subjects, those whose have either been born without a corpus callosum or had it surgically severed, it is likely that changes in performance are due to the intense corpus callosum growth seen at the ages examined above.

<u>Is a Larger Corpus callosum in Musicians due to Nature or Nurture?</u>

While the prevalence of the corpus callosum in interhemispheric function and its implications on specialized abilities are well established, the factors that influence the development of this tract currently remain nebulous. Though it has been established that the corpus callosum of musicians is larger than that of non-musicians, it has not been demonstrated whether this is due to nature or nurture. It is possible that a larger corpus callosum is a marker of musicality, drawing children to study and persist with a musical instrument. On the other hand, it is also possible that the larger corpus callosum is a function of the intensive training which involves coordination of both hands. The goal of the research reported here is to determine whether children just beginning a musical instrument start out with a larger corpus callosum (which would provide support for the nature position) or whether they start out with a typical corpus callosum (which would provide support for the nurture position).

Indirect Evidence for Nature from Retrospective Studies of Musicians.

As mentioned above, Schlaug (1995) demonstrated that the anterior corpus callosum was significantly larger in musicians than in non-musicians and that the difference was attributable to the subgroup of musicians who began training before age seven. This finding could have a genetic explanation. Perhaps those children born with a larger corpus callosum have more musical ability and would thus be drawn to initiate music lessons at an earlier age than those with a normal sized corpus callosum.

Indirect Evidence for Nurture from Animal Studies.

Several animal studies lend credence to the notion that environment gives rise to cortical plasticity and hence provide support for the nurture position with respect to the corpus callosum. Cognitive and motor skill acquisition typically lead to the enlargement of the area which holds the functional properties necessary for performance of the task. Rats who learn motor skills on an obstacle course requiring balance and coordination showed increased thickness in the motor cortex in two anterior coronal planes know to represent the hind-limbs compared to groups who were given access to an exercise wheel or simply handled on a daily basis. The exercise group showed increased thickness in the medial region of the cortex presumably due to the sensation and production of repetitive movements (Anderson, 2002).

Male infant rats that are regularly handled show a larger corpus callosum area at 110 days than non-handled controls (Berrebi, 1988). Although these effects faded by 215 days, it is clear that regular handling can influence a particular early stage of callosal progress In support of this idea, rats of both sexes at 55 days of age raised in complex, social environments show a larger posterior third of the corpus callosum than did gender matched rats raised in isolation (Juraska, 1988).

These animal findings demonstrate that varying degrees of motor stimulation can differently effect the growth of the corpus callosum in the early stages of postnatal development. These experience-based differences in corpus callosum size in young rats would indicate that use-dependent changes in childhood could also be responsible for differences in the corpus callosums of adult humans.

Considering that both corpus callosum size and finger development show their most rapid gains between the ages of four and eleven, the most probable cause for increased corpus callosum size in musicians beginning training before age seven would be that there is a large amount of use-dependent plasticity involved in development of the corpus callosum as well as in other cortical areas. If so, then “environmental” factors, such as bimanual motor training, would determine corpus callosum size.

Design of the Present Study.

It remains to be established directly whether or not intense, early experience plays a causal role in the development of the corpus callosum in humans. The present study was designed to determine whether there are preexisting differences in corpus callosum size between children drawn to music (as indexed by their initiation of music lessons) vs. those children not beginning music lessons. If those beginning music lessons show a larger corpus callosum size, we can conclude that having a larger corpus callosum is a marker of musical interest and perhaps talent. If those beginning lessons have corpus callosums the same size as those not beginning lessons, then the larger corpus callosum size found in adult musicians is likely to be due the brain's response to musical training. I therefore compared corpus callosum size in 5-7 years olds just beginning musical training with those not beginning such training. I also compared 9-11 year olds who had a minimum of one year of instrumental training with 9-11 year olds without any musical training.

The nurture hypothesis will be supported if we find (a) no difference in corpus callosum size between the 5-7 year olds just beginning music training vs. those not beginning music training; and (b) a larger corpus callosum size in 9-11 year olds who have had music training compared to those without music training.

I also examined whether there is a relation between corpus callosum size and finger tapping skill, and whether children about to begin music lessons show superior finger skill prior to instrumental training. If finger skill is a function of instrumental training, there should be no difference in finger skill between those about to start music lessons and those in the control group. It was predicted that corpus callosum size and finger skill should correlate.

Methods

Participants

The study included three groups of 5-7 year olds and two groups of 9-11 year olds. The 5-7 year olds consisted of 46 children. Children in the 5-7 year group were recruited to form three groups. Twenty-six children of these children (16 boys, 10 girls) were recruited into the Instrumental group. These children were beginning to take lessons on either keyboard or string instruments. The Instrumental group children had a mean age of 80 months (range 59-92 mos.). Ten of 5 -7 year olds children (6 boys, 4 girls) were recruited into the Non-Instrumental group. These children were beginning a public kindergarten with an experimental music program consisting of 30 minutes of music exposure four times a week. These children were able to experiment with basic musical instruments but were not focusing on a single instrument and were not practicing at home. The 5-7 year olds in the Non-Instrumental group children had a mean age of 72 months (range =58-91 months). Ten children (6 boys, 4 girls) were recruited into the Basic Music group. These children were enrolled in either a public or private or public school and were receiving the typical minimal amount of music students in U.S. schools typically receive– one class per week lasting approximately a half hour. The Basic Music group children had a mean age of 70 months (range =61-77 months).

The nine-year-old group consisted of twenty-three children. Fifteen (6 boys, 9 girls) had been studying a musical instrument for one year or more and practicing regularly at home. These children had a mean age of 116 months (range =101-133 months). Six (2 boys, 4 girls) had received no formal music training. These children had a mean age of 118 months (range =111-125 months).

Children were recruited either through their public schools or through private music schools in which they were enrolled for individual lessons. Letters were sent out by the schools to parents describing the study, and each letter included a stamped envelope that parents could return in order to get more information about the study. Presentations to parents were also given at numerous public schools and music schools. Written advertisements were posted at music school and in the *Parents Paper*, a publication targeted to parents of young children. Families who were willing to participate for three years of testing were invited to be part of the study. Families were given the choice of participating in the complete study, or in all but the MRI session. Children whose families consented to their participation were told that they would receive $60.00 per year and would be given a CD with images of their brains after the scanning session, and each child received a paper certificate at the completion of each testing session.

Handedness

There were thirty-eight right handed children and seven left handed as assessed by which hand each child used when writing his or her name, eating, throwing a ball, and using a hammer. There was one child who used more than one hand in completing these tasks; this child was classified as mixed handed.

Socio-Economic Status

Parents were given a questionnaire on which they indicated the highest level of education completed by each parent to determine SES. Each parent was scored on the following six-point scale: (1) some high school (2) high school diploma or GED (3) some college, vocational school degree, associates degree (4) four-year college degree (BA, BS) (5) MA, MS, MBA (6) PhD, MD, JD, EdD, ThD. While education alone is not a sufficient indicator of socio-economic status, it has been used in the past as a major component of indices of SES (Hollingshead & Redlich, 1958).

Materials

The motor ability test was administered individually by one experimenter using a standard monitor and keyboard. Each test session took approximately five minutes, and testing took place at either the child's academic school or music school, or at a laboratory at the Beth Israel Deaconess Medical Center. MRI sessions took place at the Beth Israel Deaconess Medical School Neuroimaging Center. A General Electric 3 Tesla Magnetic Resonance Imaging **(**MRI) Scanner was used. A 3D magnetization prepared, rapid acquisition gradient-echo (MPRAGE) imaging sequence was first performed with a voxel resolution of 1 x 1 x 1.5 mm., with a total acquisition time of 3 mm. for the entire brain. This method involves the following steps: (1) spatial normalization of all images to a standardized anatomical space by removing differences in overall size, position, and global shape; (2) extraction of gray and white matter from the normalized images; and (3) analysis of differences in local gray and white matter volume across the whole brain (Ashburner and Friston, 2001).

Design and Procedure

Children were asked to type the five-digit number sequence 5-2-4-3-5 into a standard computer keyboard with the right and then the left hand. Colored stickers were placed on the keys and matching colored stickers were put on each of the child's fingers; the child was instructed that, for example, the finger with the red sticker always pressed the red key. Each of the child's four fingers was placed on the four consecutive number keys before the trial began to ensure that the task was executed using all four fingers and no gross hand movements. Due to an error in the administration of the test, some children were asked to follow a different sequence with the right hand (2-5-3-4-2). As a result, only the left hand was used in analyses. This was possible since the left hand was the non-dominant one in most of the subject and, thus, the more important one to study since it is more likely to show pronounced training effects (Jancke, 1997).

The number sequence was tapped into the keyboard as many times as possible in a 30-second interval. Speed was assessed by measuring the average time elapsed between keystrokes and the number of keystrokes in the 30 second interval. Accuracy was measured by adding the total number of correct sequences and the weighted number of sequence fragments (a score of .6 was given for three correct digits in sequence, .8 for four correct digits in sequence, 1.0 for an entire correct sequence). All repeated entries occurring less than 150ms before the previous keystroke were deleted under the assumption that the key had been held down. Incorrect entries in the middle of a correct sequence, which were made 150ms or less after the previous entry, were deleted and marked as finger errors. Unfortunately, many of the MRIs of the nine-year-olds used were from a previous study and no finger data was available for them, which left me unable to compare older children along this measure.

After the motor test, and sometimes in a separate session, children were given a structural MRI. A week prior to the scanning session, children were given background about the scanner experience via a short comic book and heard the noises that the scanner would make. One experimenter remained in the scanner room at all times so that the child could maintain visual contact throughout the scanning session; tactile contact was also given in the instance that the child should wish to hold the experimenter's hand.

Corpus callosum measurements from the MRI images were obtained by a single investigator who was blinded to the subjects' identity and group. Non-normalized anatomical images were analyzed using custom made software running under Matlab with an SPM99 interface tool to delineate the contour of the corpus callosum in the midsagittal images. This software allowed for correction of the misalignment of the midsagittal slice by aligning brains to the horizontal plane of the anterior commissure, posterior commissure, and to the interhemispheric fissure. This ensured that a true midsagittal slice was obtained to define the corpus callosum. Three slices, the mid-sagital slice and the slices one voxel to the left and right of the midsagittal, were measured and averaged. The corpus callosum was defined by an interactive procedure using manually determined control points. In addition to total area, seven sub-areas were calculated in Matlab. The anterior corpus callosum was defined as the sum of sub-areas one to four, and the posterior corpus callosum was defined as the sum of sub-areas five to seven.

Results

The Effects of Music Training on Corpus Callosum Size and on Skilled Left-Hand Finger Movement

In what follows, the two groups not receiving lessons were collapsed into one group, called non-instrumental, and compared to the instrumental group, those receiving music lessons. The following relationships were examined: (1) the relationship between brain volume and corpus callosum size; (2) the relationship between corpus callosum size, group and gender; (3) the relationship between duration of music training (within the instrumental group), corpus callosum size, and gender; (4) the relationship between group, finger skill, and gender; (5) the relationship between duration of music training, finger skill, and gender; (6) the relationship between corpus callosum size, finger skill, and gender.

Correlation Analyses Conducted to Test the Relation between Brain Volume and Corpus Callosum.

The first set of analyses examined whether there was a relationship between the measures of corpus callosum size and any measure of brain volume. If a relationship is found between variables, it will be necessary to correct corpus callosum measures for brain volume in subsequent analyses.

Bivariate correlations were conducted to determine whether there was a significant correlation between brain volume and each of the following dependent measures of corpus callosum size: average corpus callosum size, Area 4, Area 5, Area 6, the anterior corpus callosum, and the posterior corpus callosum.

Brain Volume

Average corpus callosum size. There was a significant correlation between the average corpus callosum size and total brain volume, $p = .005$, $r = .411$, $df = 44$.

Area 4. There was a significant correlation between Area 4 and total brain volume, $p < .001$, $r = .498$, $df = 44$.

Area 5. There was a significant correlation between Area 5 and total brain volume, $p < .001$, $r = .471$, $df = 44$.

Area 6. There was a significant correlation between Area 6 and total brain volume, $p = .002$, $r = .441$, $df = 44$.

Anterior corpus callosum. There was a significant correlation between the anterior corpus callosum and total brain volume, $p = .004$, $r = .412$, $df = 44$.

Posterior corpus callosum. There was a significant correlation between the posterior corpus callosum and total brain volume, $p = .015$, $r = .357$, $df = 44$.

White Matter

Average corpus callosum size. There was a significant correlation between the average corpus callosum size and total white matter, $p < .001$, $r = .512$, $df = 44$

Area 4. There was a significant correlation between Area 4 and total white matter, $p < .001$, $r = .562$, $df = 44$.

Area 5. There was a significant correlation between Area 5 and total white matter, $p < .001$, $r = .537$, $df = 44$.

Area 6. There was a significant correlation between Area 6 and total white matter, $p < .001$, $r = .529$, $df = 44$.

Anterior corpus callosum. There was a significant correlation between the anterior corpus callosum and total white matter, $p < .001$, $r = .513$, $df = 44$.

Posterior corpus callosum. There was a significant correlation between the posterior corpus callosum and total white matter, $p = .002$, $r = .444$, $df = 44$.

Gray Matter

Average corpus callosum size. There was a significant correlation between the average corpus callosum size and total gray matter, $p = .027$, $r = .326$, $df = 44$.

Area 4. There was a significant correlation between Area 4 and total gray matter, $p = .003$, $r = .430$, $df = 44$.

Area 5. There was a significant correlation between Area 5 and total gray matter, $p = .005$, $r = .404$, $df = 44$.

Area 6. There was a significant correlation between Area 6 and total gray matter, $p = .013$, $r = .363$, $df = 44$.

Anterior corpus callosum. There was a significant correlation between the anterior corpus callosum and total gray matter, $p = .027$, $r = .327$, $df = 44$.

Posterior corpus callosum. There was no significant correlation between the posterior corpus callosum and total gray matter, p =.056, r =.284, df =44.

Taken together, these results show that all measures of corpus callosum size correlate to all three measures of brain volume with one exception: gray matter did not correlate to the size of the posterior corpus callosum. Therefore, in the analyses that follow I include dependent measures corrected for brain volume.

Relationship between Corpus Callosum Size and Group and Gender

I next examined the effect of group (Instrumental vs. Non-Instrumental) and gender on corpus callosum size through a series of 15 Group x Gender ANOVAs, each with a different measure of corpus callosum size. The ANOVAs were performed separately for each of the following fifteen dependent variables: average corpus callosum size as determined by the average of the mid-saggital corpus callosum slice and those to the left and right of it, corpus callosum size corrected by brain volume, total brain volume, total white matter, total gray matter, Area 4, Area 4 corrected for brain volume, Area 5, Area 5 corrected for brain volume, Area 6, Area 6 corrected for brain volume, the anterior corpus callosum, the anterior corpus callosum corrected for brain volume, the posterior corpus callosum, and the posterior corpus callosum corrected for brain volume.

Average corpus callosum size. No main effects of either group, $F(1, 42)$ =1.417, MSE =7461.871, p =.241, or gender, $F(1, 42)$ =3.680, MSE =19375.919, p =.062, were revealed in using the average corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 42) = 1.741$, $MSE = 9169.080$, $p = .194$.

Corpus callosum size corrected by brain volume. No main effects of either group, $F(1, 42) = 1.869$, $MSE = 25664.203$, $p = .179$, or gender, $F(1, 42) = .029$, $MSE = 393.272$, $p = .866$, were revealed in using brain volume corrected corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 42) = .667$, $MSE = 9156.741$, $p = .419$.

Total brain volume. With total brain volume as a dependent variable, there was a main effect of gender, $F(1, 42) = 4.974$, $MSE = .060$, $p = .031$. This effect occurred because males had a larger total brain volume than did females ($M = .9839$ vs .9129). There was no effect of group, nor did group interact with gender.

White matter. With total white matter as a dependent variable, there was a main effect of gender, $F(1, 42) = 7.313$ $MSE = .013$, $p = .010$. This effect occurred because males had a larger amount of total white matter than did females ($M = .3588$ vs .3261). There was no effect of group, nor did group interact with gender.

Gray matter. No main effects of either group, $F(1, 42) = .197$, $MSE = .001$, $p = .659$, or gender, $F(1, 42) = 3.350$, $MSE = .018$, $p = .074$, were revealed when using total gray matter as a dependent variable, nor were there any interaction effects, $F(1, 42) = .456$, $MSE = .002$, $p = .503$.

Area 4. No main effects of either group, $F(1, 42) = 1.295$, $MSE = 137.812$, $p = .262$, or gender, $F(1, 42) = 3.609$, $MSE = 384.023$, $p = .064$, were revealed using Area 4 as a dependent variable, nor were there any interaction effects, $F(1, 42) = .813$, $MSE = 86.469$, $p = .372$.

Area 4 corrected for brain volume. No main effects of either group, *F*(1, 42) =2.273, *MSE* =496.794, *p* =.139, or gender, *F*(1, 42) =.191, *MSE* =41.664, *p* =.665 were revealed using Area 4 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 42) =.270, *MSE* =58.921, *p* =.606.

Area 5. With Area 5 as a dependent variable, there was a main effect of gender, *F*(1, 42) =7.291, *MSE* =671.794, *p* =.010. This effect occurred because males had a larger Area 5 than did females (*M* =56.6076 vs 48.9579). There was no effect of group, nor did group interact with gender.

Area 5 corrected for brain volume No main effects of either group, *F*(1, 42) =.556, *MSE* =112.802, *p* =.460, or gender, *F*(1, 42) =1.889, *MSE*= 383.425, *p* =.177, were revealed using Area 5 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 42) =.049, *MSE* =9.989, *p* =.826.

Area 6. With Area 6 as a dependent variable, there was a main effect of gender, *F*(1, 42) =6.695, *MSE* =668.867, *p* =.013. This effect occurred because males had a larger Area 6 than did females (*M* =47.2289 vs 39.5623). There was no effect of group, nor did group interact with gender.

Area 6 corrected for brain volume. No main effects of either group, *F*(1, 42) =1.154, *MSE* =253.580, *p* =.289, or gender, *F*(1, 42) =2.190, *MSE* =481.327, *p* =.146, were revealed using Area 6 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 42) =4.079, *MSE* =.019, *p* =.892.

Anterior corpus callosum. No main effects of either group, *F*(1, 42) =3.011, *MSE* =5207.637, *p* =.090, or gender, *F*(1, 42) =1.652, *MSE* =2857.112, *p* =.206, were revealed in using the anterior corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 42) = 1.860$, $MSE = 3216.885$, $p = .180$.

Anterior corpus callosum corrected for brain volume. With anterior corpus callosum corrected for brain volume as a dependent variable, there was a main effect of group, $F(1, 42) = 4.129$, $MSE = 16749.488$, $p = .049$. This effect occurred because instrumentals had a larger anterior corpus callosum corrected for brain volume than did non-instrumentals ($M = 448.3782$ vs 413.1658). There was no effect of gender, nor did group interact with gender.

Posterior corpus callosum. With posterior corpus callosum as a dependent variable, there was a main effect of gender, $F(1, 42) = 5.731$, $MSE = 7317.936$, $p = .021$. This effect occurred because males had a larger posterior corpus callosum than did females ($M = 259.1397$ vs 234.5369). There was no effect of group, nor did group interact with gender.

Posterior corpus callosum corrected for brain volume. No main effects of either group, $F(1, 42) = .254$, $MSE = 933.508$, $p = .617$, or gender, $F(1, 42) = .502$, $MSE = 1846.725$, $p = .483$, were revealed in using the posterior corpus callosum corrected for brain volume as a dependent variable, nor were there any interaction effects, $F(1, 42) = .305$, $MSE = 1123.390$, $p = .584$.

Taken together, these analyses show no difference in any measure of corpus callosum size between children in the Instrumental vs. Non-Instrumental groups, with one exception: the anterior corpus callosum corrected for brain volume was larger in the Instrumental group. Males showed larger total brain volume and white matter, as well as larger callosal size in Areas 5 and 6 (but not when these areas were corrected for brain volume).

Regression Analyses Conducted to Test the Relation between Corpus Callosum Size and Duration of Training

Multiple regression analyses were conducted within the Instrumental Group to evaluate the effects of length of training, gender, and the interaction of training and gender for each of the fifteen dependent measures. The training x gender interaction variable did not approach conventional levels of statistical significance in any analysis and will therefore not be discussed further. The following are taken from a simultaneous model regression analyses, each with amount of training (measured in weeks) and gender as predictor variables. There are 26 cases included in the analyses, yielding 23 degrees of freedom associated with the residual. As can be seen, there was scant evidence of effects of training or gender.

Average corpus callosum size. There was no effect of training (t= .791, df= 23, p= .437), nor was there an effect of gender (t= .231, df= 23, p= .820).

Corpus callosum size corrected by brain volume. There was no effect of training (t= .874, df= 23, p= .391), nor was there an effect of gender (t= -.705, df= 23, p= .488).

Total brain volume. There was no effect of training (t= -.033, df= 23, p= .974), nor was there an effect of gender (t= 1.323, df= 23, p= .199).

White matter. There was no effect of training (t= -.144, df= 23, p= .886), nor was there an effect of gender (t= 1.758, df= 23, p= .092).

Gray matter. There was no effect of training (*t*= .030, *df*= 23, *p*= .976), nor was there an effect of gender (*t*= 1.027, *df*= 23, *p*= .315).

Area 4. There was no effect of training (*t*= .949, *df*= 23, *p*= .353), nor was there an effect of gender (*t*= .503, *df*= 23, *p*= .620).

Area 4 corrected for brain volume. There was no effect of training (*t*= 1.133, *df*= 23, *p*= .269), nor was there an effect of gender (*t*= -.328, *df*= 23, *p*= .746).

Area 5. There was no effect of training (*t*= .513, *df*= 23, *p*= .613), nor was there an effect of gender (*t*= 1.284, *df*= 23, *p*= .212).

Area 5 corrected for brain volume. There was no effect of training (*t*= .585, *df*= 23, *p*= .565), nor was there an effect of gender (*t*= .734, *df*= 23, *p*= .470).

Area 6. There was no effect of training (*t*= .864, *df*= 23, *p*= .397), nor was there an effect of gender (*t*= 1.505, *df*= 23, *p*= .146).

Area 6 corrected for brain volume. There was no effect of training (*t*= .879, *df*= 23, *p*= .388), nor was there an effect of gender (*t*= 1.020, *df*= 23, *p*= .318).

Anterior corpus callosum. There was no effect of training (*t*= .709, *df*= 23, *p*= .485), nor was there an effect of gender (*t*= -.220, *df*= 23, *p*= .828).

Anterior corpus callosum corrected for brain volume. There was no effect of training (*t*= .792, *df*= 23, *p*= .437), nor was there an effect of gender (*t*= -1.163, *df*= 23, *p*= .257).

Posterior corpus callosum. There was no effect of training (*t*= .777, *df*= 23, *p*= .445), nor was there an effect of gender (*t*= .737, *df*= 23, *p*= .469).

Posterior corpus callosum corrected for brain volume. There was no effect of training (*t*= .831, *df*= 23, *p*= .414), nor was there an effect of gender (*t*= -.067, *df*= 23, *p*= .947).

Relationship between Group (Instrumental vs. Non-Instrumental) and Finger Skill in the Non-Dominant Hand

Five Group (2) x Gender (2) ANOVAs were performed with various measures of finger skill as the dependent variable. The two groups, consisting of only right handed subjects, were the Instrumental Group and the Non-Instrumental Group. The ANOVAs were performed separately on each of the following three dependent variables: the sum of weighted sequences across the three trials (the sum of all correct sequences and sequences fragments: 0.6 for each sequence fragment of three correct consecutive digits, 0.8 for each fragment of four correct consecutive digits), the sum of correct sequences across the three trials, and the average inter-stimulus interval (ISI) over all three runs.

Sum of weighted sequences. With the total sum of weighted sequences as a dependent variable, there was a main effect of group, F (1, 42) =11.646, MSE =277.172, p =.002. This effect occurred because the group with instrumental training had more total weighted sequences than did the non-instrumentals (M =11.725 vs 6.663). There was no effect of gender, nor did group interact with gender, F (1, 42) =.218, MSE =5.195, p =.643.

Sum of correct sequences. With the sum of correct sequences as a dependent variable, there was a main effect of group, F(1, 42) =9.974, MSE =251.172, p =.003. This effect occurred because the group with instrumental training had more total correct sequences than did the non-instrumentals (M =9.167 vs 4.333). There was no effect of gender, nor did group interact with gender, F (1, 42) =.370, MSE =9.313, p =.547.

Average ISI. No main effects of either group, F(1, 42) =2.923, MSE =2068131.945, p =.095, or gender, F(1, 42) =.055, MSE =39064.840, p =.815, were revealed in using average ISI as a dependent variable, nor were there any interaction effects, *F*(1, 42) =.024, *MSE* =17148.902, *p* =.877.

These analyses showed that on two of three measures of finger skill in the non-dominant hand, those in the Instrumental group performed more skillfully than those in the Non-Instrumental group. Given that all of the children in the Instrumental group had already had some music training, I reasoned that this group effect might not have existed prior to training but might be a direct effect of training. I therefore examined the effects of different levels of training within the Instrumental group.

<u>Effect of Music Training on Finger Skill in the Non-Dominant Hand: 12 or More Weeks vs. Under 12 Weeks</u>

To determine whether there was an effect of duration of training within the Instrumental Group, those who had received 12 weeks of training or more were compared to those who had received fewer than 12 weeks of training. The same ANOVAs reported above were performed, this time with group defined as those who had received more training vs. those who had received less, as defined above.

<u>Sum of weighted sequences.</u> No main effects of group, *F*(1, 23) =3.341, *MSE* =109.246, *p* =.083 or gender, *F*(1, 23) =.288, *MSE* =9.408, *p* =.598, were revealed using the sum of weighted sequences as a dependent variable, nor were there any interaction effects, *F*(1, 23) =.580, *MSE* =18.981, *p* =.455.

<u>Sum of correct sequences.</u> No main effect of group, *F*(1, 23) =4.198, *MSE* =138.936, *p* =.054, or gender, *F*(1, 23) =.283, *MSE* =9.386, *p* =.601, were revealed using

the sum of correct sequences as a dependent variable, not were there any interaction effects, $F(1, 23) = 1.307$, $MSE = 43.261$, $p = .266$.

Average ISI. No main effects of either group, $F(1, 23) = 2.159$, $MSE = 1577389.149$, $p = .157$, or gender, $F(1, 23) = .002$, $MSE = 1570.624$, $p = .963$, were revealed in using average ISI as a dependent variable, nor were there any interaction effects, $F(1, 23) = .047$, $MSE = 34031.367$, $p = .831$.

Unlike the first set of analyses comparing the Instrumental and Non-instrumental groups, no effects were seen on the sums of weighted or correct sequences between those children who had received more than 12 weeks of training versus those who had received less. I next examined the effect of over 16 weeks of music training.

Effect of Music Training on Finger Skill in the Non-Dominant Hand: 16 or More Weeks vs. Under 16 Weeks

To determine whether these three measures of finger skill increased further in a group with a higher level of training, the same ANOVAs were repeated, this time dividing the Instrumental Group into those who had received 16 weeks or more of training vs. those who had received fewer than 16 weeks.

Sum of weighted sequences. With the sum of weighted sequences as a dependent variable, there was a main effect of group, $F(1, 23) = 5.424$, $MSE = 159.774$, $p = .030$. This effect occurred because the group with more training had more weighted sequences than did the group with less ($M = 13.708$ vs 9.382). There was no effect of gender, nor did group interact with gender.

Sum of correct sequences. With the sum of correct sequences as a dependent variable, there was a main effect of group, $F(1, 23) = 5.401$, $MSE = 167.943$, $p = .031$. This effect occurred because the group with more training had more correct sequences than did the group with less ($M = 11.154$ vs 6.818). There was no effect of gender, nor did group interact with gender.

Average ISI. No main effects of either group, $F(1, 23) = 2.755$, $MSE = 1957796.714$, $p = .113$, or gender, $F(1, 23) = .108$, $MSE = 76788.105$, $p = .746$, were revealed in using average ISI as a dependent variable, nor were there any interaction effects, $F(1, 23) = .151$, $MSE = 107418.277$, $p = .702$.

With a higher cut off of training at 16 weeks, the same variables which showed significance in the Instrumental and Non-instrumental comparison became significant within the Instrumental group. I next examined the effect of over 25 weeks of music training.

Effect of Music Training on Finger Skill in the Non-Dominant Hand: 25 or More Weeks vs. Under 25 Weeks

To determine whether these three measures of finger skill increased further in a group with an even higher level of training, these ANOVAs were repeated again, this time dividing the Instrumental Group into those who received 25 weeks of training or more vs. those who received fewer.

Sum of weighted sequences. With the sum of weighted sequences as a dependent variable, there was a main effect of group, $F(1, 23) = 6.352$, $MSE = 185.975$, $p = .020$. This effect occurred because the group with more training had more weighted sequences than did the group with less (*M* =15.044 vs 9.733). There was no effect of gender, nor did group interact with gender.

Sum of correct sequences. With the sum of correct sequences as a dependent variable, there was a main effect of group, *F* (1, 23) =6.459, *MSE*= 199.823, *p* =.019. This effect occurred because the group with more training had more correct sequences than did the group with less (*M* =12.444 vs 7.200). There was no effect of gender, nor did group interact with gender.

Average ISI. No main effects of either group, *F*(1, 23) =2.962, *MSE* =2068405.341, *p* =.101, or gender, *F*(1, 23) =.024, *MSE* =16540.002, *p* =.879, were revealed in using average ISI as a dependent variable, nor were there any interaction effects, *F*(1, 23) =.002, *MSE* =1083.343, *p* =.969.

These analyses are consistent with the earlier ones: on the same two measures, those with 25 weeks or more of training outperformed those with under 25 weeks.

Regression Analyses Conducted to Test Relation of Training Duration to Finger Tapping Skill

I next conducted three regression analyses to determine whether amount of training predicts any of the measures of finger tapping skill. As can be seen, no measure of accuracy or speed showed a direct relationship with training by this test.

Sum of weighted sequences. With the sum of weighted sequences, there was no significant effect of training, *t* =.708, *df* =22, *p* =.244.

Sum of correct sequences. With the sum of correct sequences, there was no significant effect of training, *t* =.984, *df* =22, *p* =.336.

Average ISI. With the average ISI, there was no significant effect of training, *t* =-.902, *df* =22, *p* =.215.

Relation between Left Hand Finger Skill and Corpus Callosum.

Bivariate correlations were conducted using the sum of weighted sequences and the sum of correct sequences as independent variables to determine whether or not there was a significant correlation between left hand finger skill and the following dependent variables: average corpus callosum size, corpus callosum size corrected for brain volume, Area 4, Area 4 corrected for brain volume, Area 5, Area 5 corrected for brain volume, Area 6, Area 6 corrected for brain volume, the anterior corpus callosum, the anterior corpus callosum corrected for brain volume, the posterior corpus callosum, and the posterior corpus callosum corrected for brain volume.

Sum of weighted sequences

Average corpus callosum size. There was no significant correlation between the average corpus callosum size and the sum of weighted sequences, *p* =.421, *r* =.126, *df* =41.

Corpus callosum size corrected for brain volume. There was no significant correlation between the corpus callosum size corrected for brain volume and the sum of weighted sequences, *p* =.220, *r* =.191, *df* =41.

Area 4. There was no significant correlation between Area 4 and the sum of weighted sequences, *p* =.458, *r* =.116, *df* =41.

Area 4 corrected for brain volume. There was no significant correlation between Area 4 corrected for brain volume and the sum of weighted sequences, *p* =.176, *r* =.210, *df* =41.

Area 5. There was no significant correlation between Area 5 and the sum of weighted sequences, *p* =.740, *r* =.060, *df* =41.

Area 5 corrected for brain volume. There was no significant correlation between Area 5 corrected for brain volume and the sum of weighted sequences, *p* =.395, *r* =.133, *df* =41.

Area 6. There was no significant correlation between Area 6 and the sum of weighted sequences, *p* =.780, *r* =.044, *df* =41.

Area 6 corrected for brain volume. There was no significant correlation between Area 6 corrected for brain volume and the sum of weighted sequences, *p* =.529, *r* =.099, *df* =41.

Anterior corpus callosum. There was no significant correlation between the anterior corpus callosum and the sum of weighted sequences, *p* =.384, *r* =.136, *df* =41.

Anterior corpus callosum corrected for brain volume. There was no significant correlation between the anterior corpus callosum corrected for brain volume and the sum of weighted sequences, *p* =.183, *r* =.183, *df* =41.

Posterior corpus callosum. There was no significant correlation between the posterior corpus callosum and the sum of weighted sequences, *p* =.544, *r* =.095, *df* =41.

Posterior corpus callosum corrected for brain volume. There was no significant correlation between the posterior corpus callosum and the sum of weighted sequences, *p* =.349, *r* =.146, *df* =41.

Sum of Correct Sequences

Average corpus callosum size. There was no significant correlation between the average corpus callosum size and the sum of correct sequences, $p = .304$, $r = .162$, $df = 41$.

Corpus callosum size corrected for brain volume. There was no significant correlation between the corpus callosum size corrected for brain volume and the sum of correct sequences, $p = .110$, $r = .250$, $df = 41$.

Area 4. There was no significant correlation between Area 4 and the sum of correct sequences, $p = .484$, $r = .111$, $df = 41$.

Area 4 corrected for brain volume. There was no significant correlation between Area 4 corrected for brain volume and the sum of correct sequences, $p = .154$, $r = .224$, $df = 41$.

Area 5. There was no significant correlation between Area 5 and the sum of correct sequences, $p = .433$, $r = .124$, $df = 41$.

Area 5 corrected for brain volume. There was no significant correlation between Area 5 corrected for brain volume and the sum of correct sequences, $p = .153$, $r = .224$, $df = 41$.

Area 6. There was no significant correlation between Area 6 and the sum of correct sequences, $p = .527$, $r = .100$, $df = 41$.

Area 6 corrected for brain volume. There was no significant correlation between Area 6 corrected for brain volume and the sum of correct sequences, $p = .265$, $r = .176$, $df = 41$.

Anterior corpus callosum. There was no significant correlation between the anterior corpus callosum and the sum of correct sequences, $p = .340$, $r = .151$, $df = 41$.

Anterior corpus callosum corrected for brain volume. There was no significant correlation between the anterior corpus callosum corrected for brain volume and the sum of correct sequences, $p = .125$, $r = .241$, $df = 41$.

Posterior corpus callosum. There was no significant correlation between the posterior corpus callosum and the sum of correct sequences, *p* =.337, *r* =.152, *df* =41.

Posterior corpus callosum corrected for brain volume. There was no significant correlation between the posterior corpus callosum and the sum of correct sequences, *p* =.150, *r* =.226, *df* =41.

Contrary to prediction, these analyses show no relation between corpus callosum size and non-dominant finger skill.

Relationship between Corpus Callosum Size, Group, and Gender in Nine-Year-Olds

Fifteen Group (2) x Gender (2) ANOVAs were performed with size of various parts of the corpus callosum as the dependent variable. The two groups were the Instrumental Group, those who had been taking lessons for at least a year, and the Non-Instrumental Group, who had received no training. The ANOVAs were performed separately for each of the following fifteen dependent variables: average corpus callosum size as determined by the average of the mid-saggital corpus callosum slice and those to the left and right of it, corpus callosum size corrected by brain volume, total brain volume, white matter, gray matter, Area 4, Area 4 corrected for brain volume, Area 5, Area 5 corrected for brain volume, Area 6, Area 6 corrected for brain volume, the anterior corpus callosum, the anterior corpus callosum corrected for brain volume, the posterior corpus callosum, and the posterior corpus callosum corrected for brain volume.

Average corpus callosum size. No main effects of either group, $F(1, 19) = 2.688$, $MSE = 15772.309$, $p = .119$, or gender, $F(1, 19) = 1.878$, $MSE = 11021.062$, $p = .188$, were revealed in using the average corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 19) = .296$, $MSE = 1735.870$, $p = .594$.

Corpus callosum size corrected by brain volume. No main effects of either group, $F(1, 19) = 2.123$, $MSE = 67250.642$, $p = .163$, or gender, $F(1, 19) = .001$, $MSE = 33.069$, $p = .975$, were revealed in using brain volume corrected corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 19) = .044$, $MSE = 1380.064$, $p = .837$.

Total brain volume. No main effects of either group, $F(1, 19) = .554$, $MSE = .006$, $p = .467$, or gender, $F(1, 19) = .029$, $MSE = 2.528$, $p = .130$, were revealed in using the total brain volume as a dependent variable, nor were there any interaction effects, $F(1, 19) = .235$, $MSE = .003$, $p = .634$.

White matter. No main effects of either group, $F(1, 19) = .374$, $MSE = .000$, $p = .549$, or gender, $F(1, 19) = 3.300$, $MSE = .003$, $p = .087$, were revealed in using the total white matter as a dependent variable, nor were there any interaction effects, $F(1, 19) = .399$, $MSE = .000$, $p = .536$.

Gray matter. No main effects of either group, $F(1, 19) = .563$, $MSE = .004$, $p = .463$, or gender, $F(1, 19) = 2.025$, $MSE = .014$, $p = .173$, were revealed when using the total gray matter as a dependent variable, nor were there any interaction effects, $F(1, 19) = .164$, $MSE = .001$, $p = .690$.

Area 4. No main effects of either group, $F(1, 19) = 2.899$, $MSE = 283.714$, $p = .107$, or gender, $F(1, 19) = 4.142$, $MSE = 405.379$, $p = .058$, were revealed using Area 4 as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.238, *MSE* =23.337, *p* =.632.

Area 4 corrected for brain volume. No main effects of either group, *F*(1, 19) =2.644, *MSE* =1190.241, *p* =.122, or gender, *F*(1, 19) =.314, *MSE* =141.417, *p* =.582 were revealed using Area 4 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.055, *MSE* =24.935, *p* =.817.

Area 5. No main effects of either group, *F*(1, 19) =2.050, *MSE* =187.844, *p* =.170, or gender, *F*(1, 19) =.952, *MSE* =87.269, *p* =.343, were revealed using Area 5 as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.388, *MSE* =35.581, *p* =.541.

Area 5 corrected for brain volume No main effects of either group, *F*(1, 19) =.1.672, *MSE* =838.645, *p* =.213, or gender, *F*(1, 19) =.030, *MSE*= 14.836, *p* =.866, were revealed using Area 5 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.134, *MSE* =66.982, *p* =.719.

Area 6. No main effects of either group, *F*(1, 19) =1.635, *MSE* =149.323, *p* =.218, or gender, *F*(1, 19) =.010, *MSE* =.915, *p* =.921, were revealed using Area 6 as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.888, *MSE* =81.081, *p* =.359.

Area 6 corrected for brain volume. No main effects of either group, *F*(1, 19) =1.499, *MSE* =615.426, *p* =.238, or gender, *F*(1, 19) =.658, *MSE* =270.028, *p* =.429, were revealed using Area 6 corrected for brain volume as a dependent variable, nor were there any interaction effects, *F*(1, 19) =.418, *MSE* =171.677, *p* =.527.

Anterior corpus callosum. With anterior corpus callosum corrected for brain volume as a dependent variable, there was a main effect of gender, $F(1, 19) = 4.903$, $MSE = 8336.643$, $p = .041$. This effect occurred because males had a larger anterior corpus callosum corrected for brain volume than did females ($M = 301.883$ vs 256.123). There was no effect of group, nor did group interact with gender.

Anterior corpus callosum corrected for brain volume. No main effects of either group, $F(1, 19) = 1.974$, $MSE = 16037.153$, $p = .178$, or gender, $F(1, 19) = .424$, $MSE = 3445.478$, $p = .524$, were revealed in using the anterior corpus callosum corrected for brain volume as a dependent variable, nor were there any interaction effects, $F(1, 19) = .007$, $MSE = 60.365$, $p = .932$.

Posterior corpus callosum. No main effects of either group, $F(1, 19) = .2.374$, $MSE = 3769.732$, $p = .142$, or gender, $F(1, 19) = .182$, $MSE = 289.176$, $p = .675$, were revealed in using the posterior corpus callosum as a dependent variable, nor were there any interaction effects, $F(1, 19) = .666$, $MSE = 1057.556$, $p = .426$.

Posterior corpus callosum corrected for brain volume. No main effects of either group, $F(1, 19) = 1.865$, $MSE = 16405.649$, $p = .190$, or gender, $F(1, 19) = .402$, $MSE = 3534.985$, $p = .535$, were revealed in using the posterior corpus callosum corrected for brain volume as a dependent variable, nor were there any interaction effects, $F(1, 19) = .179$, $MSE = 1577.502$, $p = .677$.

Taken together, these results show that 9 year olds with music training did not differ from those without training on any brain measure. These findings are consistent with results from the 5-7 year olds who also showed no effect of music training on corpus callosum size.

Discussion

This study was designed to examine whether or not the increased anterior corpus callosum found in adult musicians compared to non-musicians was due to nature or nurture, as previous studies have given reason to believe that the differences could be due to either. Retrospective MRI studies have given credence to the nurture position by demonstrating that the anterior corpus callosum differences between musicians and non-musicians is attributable entirely to the subgroup of musicians who began training before age seven (Schlaug, 1995). Perhaps it was the extra music training that they received that led to the greater growth of the corpus callosum. On the other hand, since the corpus callosum is considered to be crucial for the heightened finger skills of musicians, it is possible that these subjects possessed an innately larger corpus callosum which drew them to music lessons at an earlier age.

Indirect evidence for the nurture view of differences in corpus callosum size between musicians and non-musicians comes from two sources. First there are animal studies demonstrating that rats receiving motor stimulation either from being raised in a complex environment or being handled on a regular basis show a larger corpus callosum at early stages of development (Berrebi, 1988; Juraska, 1988). The second line of evidence comes from studies which indicate that the corpus callosum continues to grow well into adolescence, experiencing its greatest gains between the ages of four and eleven (Geidd, 1996). This would make it likely that the growth of the corpus callosum is due largely to “environmental” factors such as music training.

The only group difference found in the first set of analyses, which compared measures of brain volume and corpus callosum size in the five-to-seven-year-old Instrumental and Non-Instrumental groups, was a larger anterior corpus callosum in the Instrumental group after correction for brain volume. This finding coincides with differences shown in the anterior corpus callosums of adult musicians and non-musicians and provides some support for the view that musicians begin training with a larger anterior corpus callosum, making this neurological difference a potential marker of musical talent. However, many of the children had been taking lessons for several months, making it possible that a training effect is responsible for this finding.

The following set of analyses examined differences within the Instrumental group to determine whether there were any effects of training on the size of the corpus callosum by linear regression. No effects were found along any of the dependent measures of callosal size, indicating that growth in neither the anterior corpus callosum, previously shown to be larger in the Instrumental group, nor any of the other areas is likely to be contingent upon environmental factors such as the cognitive and motor demands of playing an instrument. This finding lends credence to the notion of the anterior corpus callosum as an innate marker of musical talent, as mentioned above. However, many of the children in the Instrumental group were just beginning music training, and a significant portion (11 of 26 subjects) had begun instruction less than four months prior to the date of scanning. Thus, while the lack of training effects in this analysis supports the evaluation of the anterior corpus callosum as an inborn substrate of musical talent, it remains possible that use-dependent differences in measures of callosal size emerge over longer periods of time than were present this sample. In fact, the group differences seen here were substantially less significant than those seen in studies done on adults. This would mean that a "nurture" view of corpus callosum development could not be completely ruled out unless the growth of the corpus callosum in all the children in these two groups was monitored for the appearance of larger differences in size over a period of a year or more.

Both measures of accuracy used – the sums of weighted sequences and total correct sequences – showed strong differences between the Instrumental and Non-Instrumental groups and between the over and under 16 and 25 weeks of training subgroups within the Instrumental group. Although there were no significant effects of group or training on speed as measured by these analyses, there was a general trend toward significance with increasing musicianship. These findings show that while the range of training duration examined here is not sufficient to produce differences in callosal size, differences in finger skill emerge relatively early in the course of training.

In contrast to the group comparisons, none of the regression analyses testing the relationship of training duration and finger tapping skill revealed any significant effects. Although differences in the performance of each of the Instrumental subgroups over and under the later two of three different cut-offs would indicate a direct effect of training on performance, examination of the group means of both measures of accuracy shows that the groups who received less than 12, 16, and 25 weeks of training all scored approximately the same on both variables of accuracy. This would indicate that the effects of training shown in the previous ANOVAs are due to the skewing of data by subjects who had been taking lessons for a much longer period of time. Thus, while finger skill is a product of training, the effect emerges somewhat slowly and may not become noticeable until after six months to a year of lessons. It is probable that the range of training duration examined here is not large enough to reveal its full effect on finger skill by regression analysis.

There were no significant correlations between any of the three measures of finger skill and any measure of corpus callosum size or brain volume. This finding is contrary to the initial prediction of a relationship between corpus callosum size and non-dominant finger skill. However, previous analyses showed that while a training duration of six to twelve months was sufficient to produce increased finger skill within the Instrumental subjects, it was not enough time for significant differences in any measure of callosal size to develop. The uncoupling of finger skill and corpus callosum size noted in this paper, while certainly significant, merits more in depth examination. Increased finger skill in the non-dominant hand of adults has previously been shown to correlate with callosal size, as was mentioned earlier. However, the present task examined the performance of only unimanual dexterity at the beginning of training. It is quite possible that callosal growth could influence other aspects of musical performance, such as bimanual coordination. This development might appear as a predecessor for the increase in proficiency of the non-dominant hand, which was shown to emerge later in training.

No significant effects of either group or gender were found between the Instrumental and Non-Instrumental groups in the nine-year-olds on any measure of corpus callosum size or brain volume. Although this is contrary to predictions that might be made from the limited group effects of the anterior corpus callosum seen in the five-to-seven-year-olds, the number of nine-year-olds used was very small and the failure to uncover any effects could be due to sampling problems.

In summary, while some preliminary support was found for the idea that children possessing a larger anterior corpus callosum are more likely to be drawn into music lessons, examination of a group with children of a wider breadth of training and a more comprehensive battery of finger skill tests are needed to reach more definitive conclusions. Contrary to prediction, while instrumental music training produces increases in finger tapping accuracy in the non-dominant hand, this increase did not correlate with any measure of corpus callosum size. Taken together, this indicates that although the corpus callosum is possibly linked to cognitive aspects of music performance such as the detection of errors in pitch or timing or evaluation of spatial relationships, further investigation is needed to determine its potential role in complex finger movements.

Acknowledgements

I would like to express appreciation for the help of Gottfried Schlaug in offering me the opportunity to analyze data collected as part of the ongoing study: *Effects of Music Training on Children's Brain and Cognitive Development*, which is currently being conducted through Harvard Medical School and funded by the National Science Foundation.

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