TYPE OF MUSIC TRAINING SELECTIVELY INFLUENCES PERCEPTUAL PROCESSING

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ABSTRACT

Music training influences both brain structure and function. Musicians who began their training before age six or seven have a larger left planum temporale and corpus callosum. String players have a larger cortical representation of the left hand. Piano, singing, or rhythm instruction before age seven improves performance on spatial-temporal tasks. We sought to determine how type of music training influences perceptual processing in adults. Forty-five participants were recruited in three groups of 15: non-musician controls, percussionists, and string players. On average, musicians had played for more than thirty years and had more than 16 years of formal instruction. Participants were tested on four discrimination tasks presented in random order: auditory duration, auditory frequency, visual duration, and visual frequency. Auditory stimuli were 44.1 KHz 16-bit sine waves. Visual stimuli were vertical gratings of sinusoidally-varying brightness convolved with a Gaussian filter. On each trial, a standard stimulus was presented followed by a comparison stimulus differing in duration or frequency. An adaptive staircase procedure made the discrimination harder after correct trials and easier after incorrect trials. Each task ended when twelve errors were made. The median of the last eleven errors was selected to represent each individual's discrimination threshold. Planned comparisons were performed between groups using *t*-tests. On the auditory duration task, percussionists performed better than controls. On the auditory frequency task, string players performed better than controls. There were no statistically significant differences for the visual duration or visual frequency tasks, although there was a trend for both musician groups to perform better on the visual duration task. We conclude that type of music instruction selectively influences perceptual discrimination processes. Planned neuroimaging studies will determine the functional basis of these differential abilities.

1. BACKGROUND

Musical skill is an alliance of a number of separate and relatively independent abilities (1), and early music training has been shown to influence the brain, perception, and cognition.

1.1. Music training, brain organization, and cognitive performance

Music training can alter brain structure. The anterior corpus callosum was larger in musicians who began keyboard or string instruction before age seven compared to non-musicians or musicians who began their instruction later (2). These latter two groups did not differ, suggesting the importance of early music instruction for callosal plasticity. The authors proposed that increased inter-hemispheric communication is required to perform complex bi-manual motor sequences.

The brains of musicians also function differently. For example, a magnetoencephalography (MEG) study demonstrated that music instruction affects cortical plasticity. Dipole moments of the digits of the left hand were significantly larger in violinists compared to non-musicians (3). Larger dipole moments can indicate either greater cortical representation for that function or enhanced coherence of nerve impulses in that region. The magnitude of the effect correlated with the age when musicians began studying their instruments, and the largest effects were found for those who began instruction before age twelve. A follow-up MEG study found auditory cortex dipole moments for piano tones were enlarged by about 25% in musicians relative to non-musicians (4). Again, age of instruction onset and effect size were positively correlated: musicians who started training before age nine showed the largest effects. These authors concluded that "use-dependent functional reorganization extends across the sensory cortices to reflect the pattern of sensory input processed by the participant during development of musical skill" (p. 811).

A controversy exists about whether brain attributes related to musical skill are due to musical practice or heredity. To address this issue, researchers have used MEG to measure violinists' and trumpeters' cortical representations for violin and trumpet tones compared to sine wave tones (5). Greater representations for particular timbres were associated with the instrument of training. These data suggest that cortical representations for musical timbre are use-dependent rather than coded genetically.

Research in children supports the idea that early music training affects brain development. Children provided with piano instruction scored significantly higher than controls on spatial-temporal tasks if the instruction was provided before age 7 and continued for two years (6,7,8). Preschool children showed the largest effects (9,10). Research from other laboratories supports these findings (11). Furthermore, early music instruction emphasizing different musical skills produces specific effects on cognitive performance (12). At-risk preschool children received piano, singing, rhythm, computer, or no instruction. After two years, the three music groups scored substantially higher than the control groups on mental imagery tasks. The rhythm group, however, scored significantly higher than all other groups on tasks requiring temporal cognition and mathematical ability. These data suggest that different types of music instruction can produce different effects on cognition, with rhythm instruction having the strongest impact on temporal and sequencing tasks.

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1.2. Music training and perceptual discrimination

Several studies have examined musicians and non-musicians for differences in discrimination ability. Musicians presented with pairs of excerpts of familiar orchestral music were better able to discriminate pitch and tempo than non-musicians (13). Likewise, undergraduate music students performed better than other students on a frequency discrimination task (14). Other studies have reported better pitch discrimination for musically trained- than untrained subjects (15), and for musically trained children (16). Better duration discrimination of tones has also been reported for subjects with music training (17,18).

Musical expertise may also affect phoneme discrimination. Musicians performed better than non-musicians at processing both timbre and frequency of auditory stimuli and at identifying speech sounds (19). Musicians' expertise with musical stimuli may thus generalize to the auditory features of speech. Researchers have also reported better phoneme discrimination in tonally trained subjects (20). Although the study did not include musicians, the finding implies that music instruction can affect the ability to distinguish phonemes—the second stage in learning to read. In addition, children who received music instruction performed better on reading tasks (21,22).

These studies strongly suggest that music instruction can influence discrimination abilities, which are critical for many aspects of higher cognition. Furthermore, early music instruction is generally associated with the strongest effects. Here we report how discrimination abilities in adult musicians vary as a function of type of music instruction.

2. AIMS

This experiment examined the effects of different kinds of early music instruction by evaluating certain perceptual components of musical expertise in adults. We measured discrimination of auditory and visual duration and frequency in string players, percussionists, and non-musicians.

3. METHOD

3.1. Participants

Forty-five participants were recruited. Musicians (string: n=14; percussion: n=14; ages 16-63) had all played professionally, had 12 or more years of experience on their primary instrument, and averaged 15.64 years of formal instruction in their primary instrument. One participant from each musician group was excluded because they did not meet the criterion for years of experience. Non-musicians (n=15; ages 19-56) had no instrumental, vocal, composition, or school music instruction. Groups were matched in education and socio-economic status. All participants gave informed consent according to University of Wisconsin Oshkosh guidelines and were paid $20.

3.2. Apparatus

Auditory and visual stimuli were generated and presented on an IBM-compatible personal computer. Auditory stimuli were presented binaurally on stereo headphones, and the computer keyboard was used to record responses.

3.3. Stimuli

Auditory stimuli were 16-bit stereo sound files sampled at 44.1 KHz. All were pure-tone sine waves with 5 ms leading and trailing ramps to produce smooth perceptual transitions. Visual stimuli were 480 x 480 pixel grayscale bitmaps of vertical sine wave gratings convolved with a Gaussian filter and presented on a black background (Figure 1). The 100 comparison stimuli varied symmetrically and proportionally around the standard

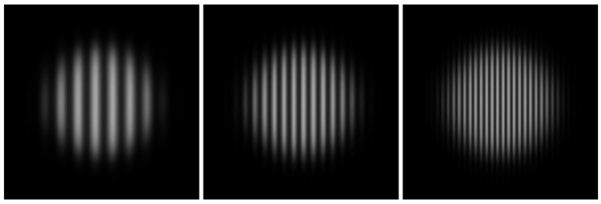

Figure 1: The VF low- and high-frequency comparison stimuli (left and right) and the standard visual stimulus (center).

according to a ratio rule. In addition, stimuli were distributed parabolically to allow refined assessment across a wide range of thresholds (Figure 2). For frequency discriminations, auditory stimuli ranged from 415.39 to 466.07 Hz (approximately A-flat to A-sharp) with the standard stimulus at 440.00 Hz, and visual stimuli ranged from 11.25 to 35.57 Hz with the standard set at 20.00 Hz. For duration discriminations, both auditory and visual stimuli varied from 562 to 1778 ms, and the standard duration was 1000 ms. The most difficult pitch discriminations were 0.01 Hz, and the most difficult visual frequency discriminations were 0.005 Hz. The most difficult duration discrimination in both modalities was 1 ms.

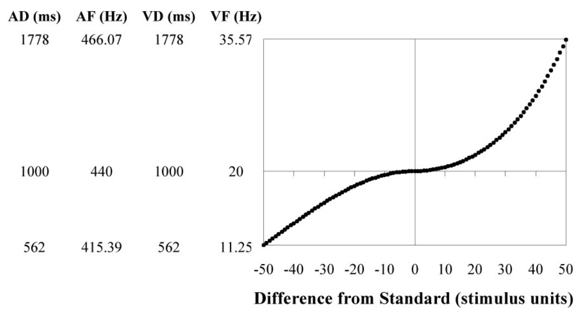

Figure 2. Comparison stimuli varied symmetrically and inversely around the standard such that the task became geometrically more difficult as the standard was neared.

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3.4. Procedure

The four discrimination tasks (auditory duration [AD], auditory frequency [AF], visual duration [VD], and visual frequency [VF]) were presented in random order. An adaptive testing method (23) determined participants' discrimination thresholds. This method uses a "three-up, one-down" principle, in which the discrimination is made substantially easier when an error is made and somewhat harder after a correct response. The procedure converges on the participant's threshold for 75% accuracy. Each task began with an easy discrimination and then task difficulty increased geometrically until an error was made.

Each trial consisted of the standard stimulus followed 1 s later by a comparison stimulus. For auditory discrimination, the task was to indicate whether the comparison stimulus was shorter or longer in duration or lower or higher in pitch. For visual discrimination, the task was to indicate whether the comparison stimulus was shorter or longer in duration or lower or higher in spatial frequency. The first comparison stimulus was either 48 steps above or below the standard, and its position relative to the standard varied randomly from trial to trial. The first five trials halved the stimulus number after each correct response (*e.g.*, five correct responses would change the comparison stimulus from +/-48 to +/-24 to +/-12 to +/-6 to +/-3 units from the standard). If an error was made on trials 2 through 4, the difference between the comparison and standard stimuli increased by 50%. Following the first error or on the fifth correct trial, the "three-up, one-down" principle came into effect. Each task ended when a participant made 12 errors.

4. RESULTS

We calculated the absolute difference between the comparison and standard in ms or Hz for each error. The median of the last 11 errors estimated the participant's 75% discrimination threshold. Group means are displayed in Figure 3.

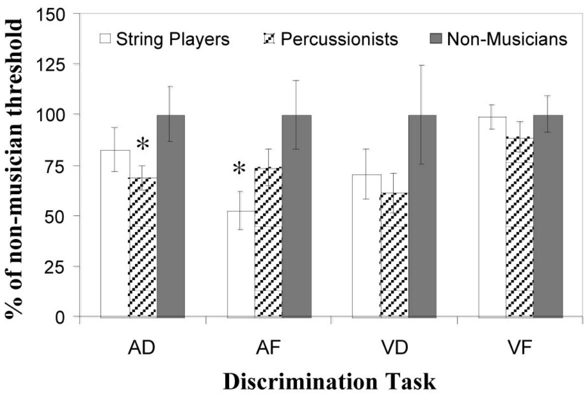

Figure 3. Discrimination thresholds for string players and percussionists on the four tasks are normalized relative to the performance of the non-musicians. Error bars are standard errors of the mean. Asterisks indicate significant differences from non-musician discrimination thresholds ($p < .05$).

Musicians had lower discrimination thresholds than non-musicians for all tasks, although the difference was significant only for AF ($p = .02$). The difference between musicians' and non-musicians' AD thresholds approached significance ($p = .07$). Musicians and non-musicians did not differ for VF ($p = .52$) or VD ($p = .11$). Percussionists had lower AD thresholds than non-musicians ($p = .05$). String players had lower AF thresholds than non-musicians ($p = .02$). Percussionists' discrimination thresholds were lower than string players' on AD and VD, and string players' thresholds were lower than percussionists' on AF, although these differences were not significant. For string players, years of instruction correlated significantly with both AD ($r = -.74$, $p = .002$) and AF ($r = -.55$, $p = .04$), and age of instruction onset correlated significantly with AD ($r = .56$, $p = .04$) and AF ($r = .64$, $p = .01$) as well.

5. CONCLUSIONS

Musicians' auditory discrimination thresholds were lower than those of non-musicians, although the difference did not quite reach significance for auditory duration. Visual frequency thresholds of musicians and non-musicians did not significantly differ. The lack of difference on this control task demonstrates that discrimination differences in musicians are specific to the domains that music training emphasizes. Percussionists' duration thresholds in both modalities were lower than those of string players and non-musicians, as might be expected from the emphasis their training places on sensitivity to time. String players' auditory frequency thresholds were lower than those of percussionists and non-musicians. This observation is consistent with the many years of fine tonal discrimination training that string players receive and the fact that they actively tune their instrument. Compared to non-musicians, percussionists had lower auditory duration thresholds and string players had lower auditory frequency thresholds (Figure 3). These findings suggest that expertise in a musical instrument selectively improves discrimination thresholds corresponding to the skills emphasized by training in that instrument.

We had no specific predictions regarding how age of instruction onset and years of instruction would correlate with our dependent variables. However, the significant correlations between these variables and the auditory thresholds for string players imply a developmental trend. Twelve of the 14 string players, but only three of the percussionists, began music instruction before age eight. The mean age of instruction onset for string players was 5.7, whereas for percussionists it was 10.7, a significant difference. Furthermore, the mean number of years of instruction was 18.0 for string players and 13.3 for percussionists ($p = .04$). Perhaps earlier age of instruction onset or more years of instruction improve auditory discrimination, a hypothesis we will examine in a future study.

These data show that professional musicians possess superior auditory discrimination specific to the musical instrument they play. This observation suggests that cognitive differences in professional musicians are influenced by the nature of their training in their primary instrument. Age of onset and years of instruction are correlated with auditory thresholds for string

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players. These findings support the idea that earlier music instruction or more years of training results in more refined discrimination. Onset age is confounded with group in this experiment because string players began instruction earlier and studied longer than percussionists. Onset age will be treated as an independent variable in future studies to directly assess its effects on discrimination thresholds in musicians.

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