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Music training leads to the development of timbre-specific gamma band activity

Antoine J. Shahin,[a,*] Larry E. Roberts,[b,c] Wilkin Chau,[d] Laurel J. Trainor,[b,d] and Lee M. Miller[a,e]

[a]University of California, Davis Center for Mind and Brain, 267 Cousteau Place, Davis, CA 95618, USA
[b]Department of Psychology, Neuroscience and Behaviour, McMaster University, Hamilton, Ontario, Canada
[c]MEG Neuroscience Unit, Down Syndrome Research Foundation, Burnaby, British Columbia, Canada
[d]Rotman Research Institute of Baycrest, Toronto, Ontario, Canada
[e]University of California, Section of Neurobiology, Physiology, and Behavior, Davis, CA, USA

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Oscillatory gamma band activity (GBA, 30–100 Hz) has been shown to correlate with perceptual and cognitive phenomena including feature binding, template matching, and learning and memory formation. We hypothesized that if GBA reflects highly learned perceptual template matching, we should observe its development in musicians specific to the timbre of their instrument of practice. EEG was recorded in adult professional violinists and amateur pianists as well as in 4- and 5-year-old children studying piano in the Suzuki method before they commenced music lessons and 1 year later. The adult musicians showed robust enhancement of induced (non-time-locked) GBA, specifically to their instrument of practice, with the strongest effect in professional violinists. Consistent with this result, the children receiving piano lessons exhibited increased power of induced GBA for piano tones with 1 year of training, while children not taking lessons showed no effect. In comparison to induced GBA, evoked (time-locked) gamma band activity (30–90 Hz, ~80 ms latency) was present only in adult groups. Evoked GBA was more pronounced in musicians than non-musicians, with synchronization equally exhibited for violin and piano tones but enhanced for these tones compared to pure tones. Evoked gamma activity may index the physical properties of a sound and is modulated by acoustical training, while induced GBA may reflect higher perceptual learning and is shaped by specific auditory experiences.

Keywords: Auditory cortex; Development; Gamma band activity; Music training; Plasticity; Timbre-specificity

Musicians possess heightened perceptual abilities, typically acquired through years of practice. As such, musicians represent a good model of how our brains adapt with experience (Münte et al., 2002). We sought to identify what differentiates the brains of musicians from non-musicians when listening to sounds of their practiced instrument, and whether such attributes are acquired through music training.

Cortical responses to sound occur as early as 19 ms after sound onset and continue at various latencies reflecting activation of serial and parallel stages of processing in the auditory system. Many of these responses, including auditory "middle latency" responses (~19–80 ms) and the longer latency N1/N1m (100 ms, N1m designating the magnetic counterpart of the electrical N1), N1c (140 ms), P2 (180 ms), and N2m (250 ms) responses, have been shown from electromagnetic studies to be enhanced in young and adult musicians compared to non-musicians (middle latency: Schneider et al., 2002; Shahin et al., 2004; N1c: Shahin et al., 2003; N1m: Pantev et al., 1998; N2m: Fujioka et al., 2006; P2: Shahin et al., 2003, 2004, 2005; P2m: Shahin et al., 2005; Kuriki et al., 2006). Enhancement of the middle latency N19m-P30m response in musicians has been shown to parallel an increase of gray matter in Heschl's gyrus, suggesting an enhanced neural population in trained musicians (Schneider et al., 2002, 2005). In principle, these distinct processes in musicians could be inherited and/or learned during the musicians' training history, reflecting improved performance through neural plasticity (Weinberger, 2003). Recent studies revealed that some of these components are enhanced following short term training on auditory discrimination tasks (N1m: Menning et al., 2000; N1c: Bosnyak et al., 2004; P2: Tremblay et al., 2001 and Bosnyak et al., 2004) pointing to their susceptibility to neuroplastic influence.

Brain responses measured in the above studies reflect synchronous neural activity time-locked to the stimulus ("evoked" responses) and may represent specific physical features of the acoustical cues (Näätänen and Picton, 1987). However, acoustic stimulation elicits oscillatory brain responses that are not time-locked to stimulus events ("induced" responses) (Bertrand and

* Corresponding author. Fax: +1 530 297 4603.
E-mail address: ajshahin@ucdavis.edu (A.J. Shahin).
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Tallon-Baudry, 2000) and can only be detected in single trial data. Such responses of the gamma frequency band (30–100 Hz) induced by visual stimuli are widely believed to reflect network activity that binds features to form conscious percepts (Singer and Gray, 1995; Tallon-Baudry et al., 1996). The functional significance of induced gamma band activity (GBA) in the auditory domain is less well understood. In one study of the auditory system (Bhattacharya et al., 2001) amateur musicians displayed increased long-range synchrony in the gamma range (30–50 Hz) when listening to a musical piece but not to a novel story, suggesting that synchronous activity may have reflected an advanced ability to bind musical features such as pitch, timbre, and harmony. Induced auditory GBA has also been linked to attention, anticipation and expectation (Sokolov et al., 2004; Snyder and Large, 2005; Zanto et al., 2005). Attentional processing occurs at the time of expected beats in a rhythm pattern, even if the beats are occasionally omitted (Snyder and Large, 2005).

The presence of distinct EEG attributes in musicians invites the hypothesis that musical training modifies a neural system for auditory information processing. If acoustic feature processing expressed in oscillatory activity is a function of auditory learning, we would expect to observe enhanced GBA in musicians specific to the timbre of their instrument of practice. We examined evoked and induced oscillatory gamma band activity recorded in the electroencephalogram (EEG) of professional violinists, amateur pianists, and age-matched non-musicians while passively listening to violin, piano, and pure tones matched in pitch. To establish whether oscillatory activity is affected by musical training (e.g. acquired rather than inherited), we examined GBA in 4- to 5-year-old piano pupils enrolled in a Suzuki music school before they started their musical practice and 1 year after. Age-matched children not undergoing musical training were also measured before and after an interval of 1 year.

Methods

The data used for this study were collected by Shahin et al. (2003, 2004) but subjected to different analyses here.

Participants

The adult musicians' groups consisted of 11 professional violinists (mean age ± S.D., 24.3 ± 2.2 years; six females) who were members of Canada's National Academy Orchestra and nine amateur pianists (23 ± 2.5 years; eight females) with a grade 10 certification from Canada's Royal Conservatory of Music. The adult non-musicians ($n = 14$) were McMaster University students (22.2 ± 3.4 years; eight females) who had no formal musical training. Violinists and pianists had played their instruments for an average of 17 ± 3.7 years and 16.6 ± 4.0 years, respectively, and practiced for 34.7 ± 20.8 and 17.9 ± 11.1 h/week, respectively, at the time of the study. All adult subjects except one pianist and one control reported that they were right-handed. The Suzuki pupils consisted of six pianists from the Suzuki School of Music in Hamilton, Ontario (mean age 4.6 ± 0.4 and 5.6 ± 0.5 years at the first and second measurements, respectively; three females) and six age-matched control children with no musical training (4.8 ± 0.4 and 5.6 ± 0.5 years of age at the first and second measurements, respectively; three females). Normal auditory thresholds were confirmed for all participants by a staircase procedure (<25 dB at 0.25–8.0 kHz). The adult subjects were the same participants involved in Shahin et al. (2003), and the children participants were the same reported in Shahin et al. (2004). Subjects gave written informed consent in accordance with the Research Ethics Board of McMaster University. For children, consent was also obtained from a parent.

Stimuli

The stimuli were the same as Shahin et al. (2003, 2004) and consisted of 2 violin, 2 piano and 2 pure tones each of 500 ms duration. The two violin and piano tones had fundamental frequencies of A3 = 220 Hz and C3 = 131 Hz (American notation). The pure tones were matched in frequency to the fundamental frequency of the music tones. The violin tones were taken from Kyma software and the piano tones were obtained from a Korg 01W synthesizer. Pure tones were created with a cosine envelope, with a 20-ms rise and fall time. All tones were presented at 70 dB SPL.

Procedure

Testing was performed in a sound-attenuated and electrically shielded room. The Suzuki students were tested twice, the first time just prior to the commencement of music lessons and the second time 1 year later. The control children measurements matched the time line of the Suzuki children. Adult musicians were tested once. The stimulus procedure was the same for the adults and the children. Tones were presented from a speaker placed at eye level 1 m in front of the subject in a single experimental session that lasted about 45 min. Tones were delivered in a pseudorandomized order using a constant inter-stimulus interval of 2.5 s offset to onset (720 stimuli overall, 120 for each of the six tone types). A passive listening protocol was followed in which adult subjects read a magazine or newspaper and young children watched a silent movie while the tones were presented.

The EEG was recorded using a 10–20 system 32-channel EEG cap (adults) and a 19-channel EEG cap (children). EEG recordings were sampled at 1 kHz (DC to 100 Hz; SynAmps amplifier; Neuroscan, El Paso, TX) and referenced to Cz with a ground at AFz. Channel impedances were reduced to less than 10 kΩ.

Data analysis

Channels with excessive artifacts in any subject were taken out of the analysis across all subjects. The final electrode configuration for children was as follows: frontal FP1, FP2, Fz, F3, F4; anterior–temporal F7, F8; central Cz, C3, C4; temporal T7, T8; parietal Pz, P3, P4, P7, P8. The adults' channel configuration included the above channels as well as the frontal channel FPz, occipital channels Oz, O1, O2; fronto-central channels FC5, FC6; and the posterior channels CB1, CB2, and Iz. Remaining data were high pass filtered at 1 Hz and subjected to further artifact rejection to remove ocular and muscle artifacts. Single trials with shifts of ±75 μV at channels FP1, FP2, F7, F8, T7, T8, P7, P8, were rejected in adults. For children, the artifact shift criterion at the above channels was relaxed to ±100 μV.

Time–frequency analysis

EEG files were segmented into 1200-ms epochs including a 400-ms pre-stimulus baseline. All channels were re-referenced to an average reference and baseline-corrected to the pre-stimulus interval. Time–frequency analyses of single trial data were