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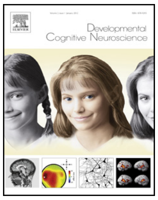

Music training relates to the development of neural mechanisms of selective auditory attention

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ABSTRACT

Selective attention decreases trial-to-trial variability in cortical auditory-evoked activity. This effect increases over the course of maturation, potentially reflecting the gradual development of selective attention and inhibitory control. Work in adults indicates that music training may alter the development of this neural response characteristic, especially over brain regions associated with executive control: in adult musicians, attention decreases variability in auditory-evoked responses recorded over prefrontal cortex to a greater extent than in nonmusicians. We aimed to determine whether this musician-associated effect emerges during childhood, when selective attention and inhibitory control are under development. We compared cortical auditory-evoked variability to attended and ignored speech streams in musicians and nonmusicians across three age groups: preschoolers, school-aged children and young adults. Results reveal that childhood music training is associated with reduced auditory-evoked response variability recorded over prefrontal cortex during selective auditory attention in school-aged child and adult musicians. Preschoolers, on the other hand, demonstrate no impact of selective attention on cortical response variability and no musician distinctions. This finding is consistent with the gradual emergence of attention during this period and may suggest no pre-existing differences in this attention-related cortical metric between children who undergo music training and those who do not.

1. Introduction

Sensory function involves the neuronal filtering of a signal of interest from competing sources of stimulation, often occurring within the same sensory domain. This filtering can be guided by selective attention, which plays a dynamic gatekeeping role by modulating neural responses to sensory input to bring about awareness of the most behaviorally-relevant environmental elements and the suppression of others. While both cellular approaches in animal models and far-field recordings in humans yield insights into how neural activity can be modified by

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selective attention, we cannot yet model all components involved in this filtering process. Influences of life factors such as maturation and sensory enrichment on attention's underlying biology provide additional factors that must be incorporated into a reliable model (e.g., Booth et al., 2003; Coch et al., 2005; Patston et al., 2007; Stevens et al., 2009; Strait and Kraus, 2011a; Strait et al., 2014a).

Most commonly, electrophysiological studies of selective attention, at both single-cell and population levels, have considered averaged sensory-evoked activity, comparing averaged responses comprising hundreds of trials to attended and concurrently ignored inputs. This approach emphasizes those aspects of the response that occur consistently but limits the assessment of attention's effects on aspects of the response that vary from trial to trial. Consideration of response variability in itself may provide insights into how the brain responds to differing sensory demands (Reich et al., 1997; Steinmetz et al., 2000), maturational changes (Gogtay et al., 2004; Li et al., 2001), and neuromodulatory influences (Jacob et al., 2013)—moving us toward a more comprehensive model of the attentive brain.

We previously assessed the variability of scalp-recorded auditory-evoked activity during a selective attention task in adults and reported that, across the scalp, evoked responses to attended speech demonstrate less between-trial variability than responses to ignored speech (Strait and Kraus, 2011a). A reduction in response variability with attention had previously been reported in other domains, such as the somatosensory (Steinmetz et al., 2000) and visual systems (Fries et al., 2001, 2008), and more recently within auditory cortex during an interval discrimination task (Abolafia et al., 2013). Rather than "turning up the volume" of neural responses to attended input by increasing the size of the recruited neural population, selective attention fine-tunes the encoding of a target signal by synchronizing brain activity and reducing its variability over time, effectively increasing its signal-to-noise ratio.

The application of this same paradigm to children revealed that attention's effect on response variability increases with age (Strait et al., 2014a), from ages three to 35, and may provide an objective index of the development of selective attention and inhibitory control. The development of this effect may be shaped by training and sensory enrichment, such as that associated with music training: in adults, the degree to which attention decreases prefrontal response variability relates to musicianship (Strait and Kraus, 2011a). Whereas musicians and nonmusicians demonstrate equivalent variability in responses across the majority of the scalp, only musically-trained adults demonstrate decreases in prefrontal response variability with attention (Strait and Kraus, 2011a). Attention-related enhancements in musicians' auditory-evoked activity have also been reported by other laboratories using alternate cortical metrics, including mismatch negativity (Besson et al., 2011; Putkinen et al., 2013b; Tervaniemi et al., 2009) and the magnitude of late cortical auditory-evoked responses (Zendel and Alain, 2011).

Here we aimed to determine whether the auditory expertise engendered by music training during early childhood alters the development of this cortical index of selective auditory attention. To this end we assessed the between-trial variability of scalp-recorded auditory-evoked activity in 77 musicians and nonmusicians between the ages of three to 35. We hypothesized that music training during early childhood is associated with the development of strengthened neural networks underlying auditory attention during mid-childhood, following the stabilization of attention ability (~age seven; Booth et al., 2003; Tipper et al., 1989). Supposing that differences between musicians and nonmusicians reflect their training, at least in part, we further predicted that: (1) young children just initiating music training would not yet demonstrate musician-associated enhancements and (2) the extent to which prefrontal response variability decreases with selective attention would be greater in children and adults with more years of musical practice relative to peers with less training.

2. Methods

2.1. Participants

All experimental procedures were approved by the Northwestern University Institutional Review Board. Seventy-eight normal hearing children and adults (<20 dB pure tone thresholds at octave frequencies from 125 to 8000 Hz) between the ages of three and 35 years participated in this study and were grouped according to three age categories: preschoolers (3–5 year olds, $N = 26$), school-aged children (7–13 year olds, $N = 29$) and adults (18–35 year olds, $N = 23$). Subjects were recruited through various mechanisms, including but not limited to flyers, advertisements in school newsletters, relationships with area music teachers, and presentations given to early childhood music programs. The subject population overlapped with the cohort of a previously published report demonstrating interacting effects of age and attention on cortical response variability (Strait et al., 2014a) with the addition of preschool ($N = 2$), school-aged child ($N = 1$) and adult ($N = 2$) subjects and the omission of one adult who fit into neither the musician nor nonmusician categories. Participants and, in the case of minors, legal guardians provided informed consent and assent. Participants were monetarily compensated for their time. No participant reported a history of neurological or learning abnormalities.

Subjects within each age group were further categorized as musicians (Mus) or nonmusicians (NonMus). Mus and NonMus did not differ according to age, sex or IQ in any of the three age groups (Table 1). Musicians were currently undergoing private or, in the case of some preschoolers, group music training (e.g., Kindermusik, Orff music classes). Adult musicians ($N = 13$) began music training by age 10 ($M = 5.6$ years, SD = 1.63; years practiced $M = 16.6$, SD = 5.54) and had no significant lapses in their practice histories. School-aged child musicians ($N = 17$) began music training by age six ($M = 4.3$ years, SD = 1.69; years practiced: $M = 7.8$, SD = 2.11) and had consistently practiced for a minimum of twelve consecutive months leading up to the date of test. Adult musicians practiced a minimum of three days per week for ≥1 h per session whereas school-aged child musicians practiced for a minimum of 20 min per day five days per week. Preschool musicians ($N = 14$) had