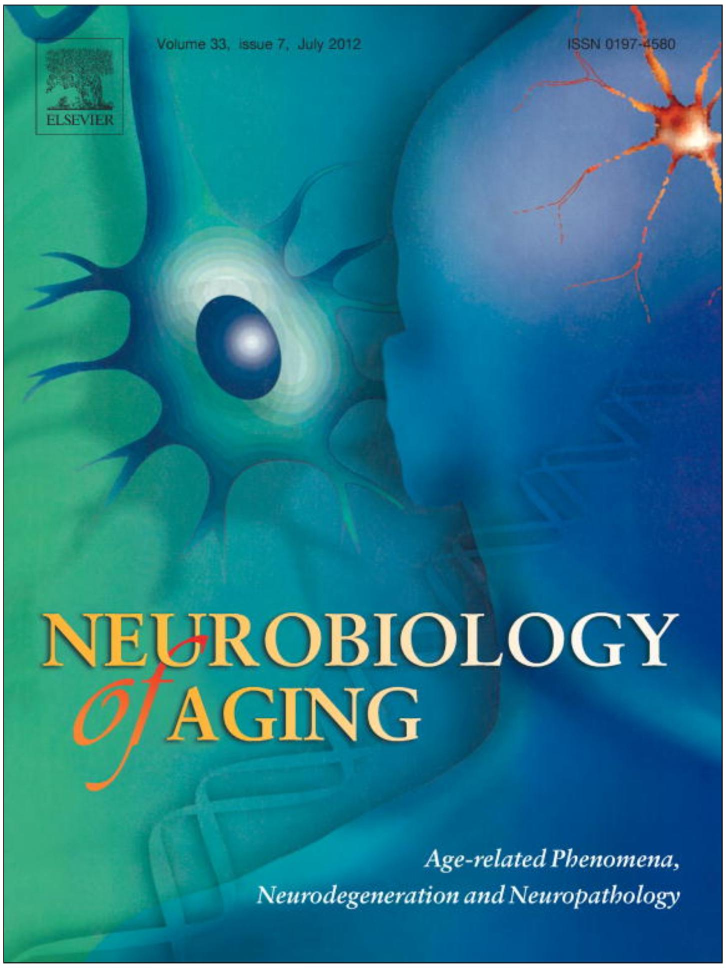
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Musical experience offsets age-related delays in neural timing

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Abstract

Aging disrupts neural timing, reducing the nervous system's ability to precisely encode sound. Given that the neural representation of temporal features is strengthened with musical training in young adults, can musical training offset the negative impact of aging on neural processing? By comparing auditory brainstem timing in younger and older musicians and nonmusicians to a consonant-vowel speech sound /da/. we document a musician's resilience to age-related delays in neural timing.

Keywords: Aging; Auditory brainstem response; Plasticity; Music

1. Introduction

Along the auditory pathway, neurons respond to sound in a stimulus-synchronized manner, with subcortical structures displaying submillisecond temporal accuracy an order of magnitude greater than other sensory systems (Frisina, 2001; Walton, 2010; Wang, 2007). This subcortical precision is important for capturing fast-changing acoustic transitions, such as those that characterize speech. However, neural precision (Frisina and Walton, 2006) and auditory temporal processing (Grose et al., 2006; Strouse et al. 1998) decline with age, potentially contributing to the problems older adults report for speech comprehension (Frisina, 2010; Gordon-Salant and Fitzgibbons, 1993).

Growing evidence from young adults indicates that musical training improves the neural representation of key acoustic features important for speech perception, highlighting the effects of lifelong training on the brain (Kraus and Chandrasekaran, 2010). Here, we asked whether musical experience offsets the decline in neural precision that occurs during the natural aging process. To address this question, we examined subcortical speech-evoked responses in a group of younger (18–32 years) and older (45–65 years) normal-hearing musicians and nonmusicians. Given their extensive engagement with sound across their lifetimes, we hypothesized that older musicians demonstrate less age-related decline in subcortical temporal precision than older nonmusicians.

2. Methods

2.1. Subjects

Eighty-seven adults participated in this study: 50 younger participants (18–32 years, mean age: 23 ± 4 years) and 37 older participants (46–65 years, mean age 56 ± 5 years). All subjects had normal hearing (see Fig. 1, octave frequencies from 0.125 to 4 kHz bilaterally ≤ 20 dB HL, pure tone average ≤ 10 dB HL), were native English speakers, and did not report neurological or learning disorders, history of chemotherapy or ototoxic medication, major surgeries, or head trauma. All subjects had normal nonverbal IQ (younger: Test of Nonverbal Intelligence; older: Abbreviated Wechsler's Adult Scale of Intelligence's matrix reasoning subtest). Sub-

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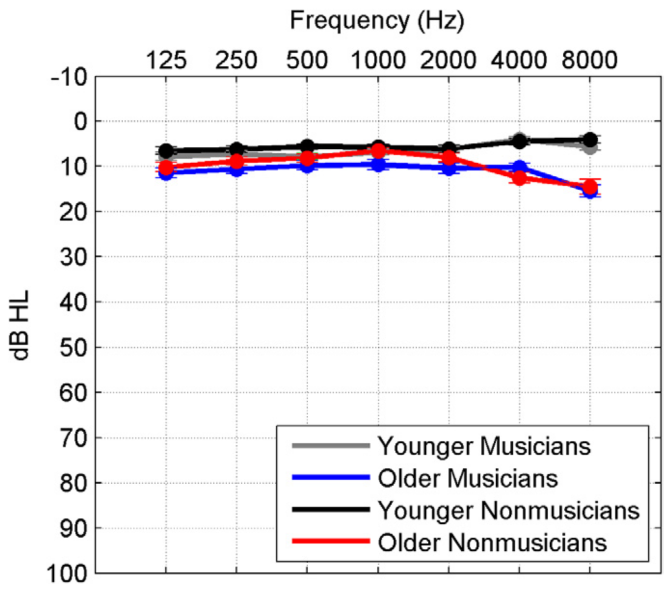

Fig. 1. Mean pure-tone thresholds (average of right and left) for younger and older musicians and nonmusicians from 125 to 8000 Hz. As expected the older groups, despite clinically normal hearing, demonstrated higher thresholds for all frequencies measured; however, within the younger and older groups, the musicians and nonmusicians had equivalent hearing. Error bars equal 1 standard error of measurement (SEM).

jects gave informed written consent in accordance with the Northwestern University's Institutional Review Board.

All musicians (46: 26 younger, 20 older) started musical training before the age of 9 and consistently engaged in musical activities (practice, performance, or teaching) for a minimum of 3 times a week throughout their lifetimes. Of the total 41 nonmusician subjects (24 younger, 17 older), 27 had no musical training (15 younger, 12 older), whereas the remaining 14 (9 younger, 5 older) had fewer than 3 years of musical experience. Within the younger and the older groups (see Table 1 for further group characteristics), musicians and nonmusicians did not differ in age, hearing, sex, or IQ (all $p > 0.1$).

2.2. *Subcortical response measures*

To explore the effect of aging on a speech sound containing both rapid formant transition changes and a steady-state vowel, we chose to use a 170-ms 6-formant consonant-vowel syllable /da/. This syllable has a steady fundamental frequency (F_0 = 100 Hz) except for an initial 5 ms (*onset*) burst. During the first 50 ms (*transition* between the stop burst [d] and the vowel [a]), the lower 3 formants change over time (F_1: 400–720 Hz; F_2: 1700–1240 Hz; F_3: 2580–2500 Hz) but stabilize for the 120 ms *steady-state vowel*. The upper 3 formants are constant throughout (F_4: 3300 Hz; F_5: 3750 Hz; F_6: 4900 Hz). Subcortical responses were differentially recorded at a 20 kHz sampling rate by Ag–AgCl electrodes in a vertical montage using Scan 4.3 (Compumedics, Charlotte, NC) with an electrode contact impedance < 5 kΩ. Stimuli were presented binaurally at 80 dB SPL through ER-3 insert earphones (Etymotic Research, Elk Grove Village, IL) at a rate of 3.95 per second. Stimuli were presented in alternating polarities, and responses were summed to limit the inclusion of stimulus artifact and cochlear microphonic (Skoe and Kraus, 2010). During the recording session (~26 ± 2 minutes), participants watched a silent, captioned movie of their choice to facilitate a wakeful yet still state. Responses were offline, band-pass filtered from 70 to 2000 Hz (12 dB roll-off, zero phase-shift) using NeuroScan Edit 4.3 and epoched from −40 to 213 ms (referenced to stimulus onset). Responses with amplitudes beyond ± 35 μV were considered artifact and rejected, resulting in 6000 response trials for each subject. Peak latencies corresponding to the onset (1 peak), transition (4 peaks), and steady state (10 peaks) were identified in the average responses by the first 3 authors blind to the subjects' group status.

3. Results

To investigate neural timing, we identified peaks in the subcortical response generated by synchronous neural firing to the speech syllable [da] (Fig. 2A). Aging differentially delayed the neural response to the formant transition (30–70 ms, 4 peaks), the most complex and information-bearing portion of our stimulus, in musicians relative to nonmusicians [$2_{Age} \times 2_{Musicianship}$ multivariate analysis of variance (MANOVA); Interaction: $F(1,83) = 2.659$, $p = 0.039$ (Fig. 2E); Age: $F(1,83) = 4.642$, $p = 0.002$; Musicianship: $F(1,83) = 6.016$, $p < 0.001$]. Although younger and older musicians exhibited equivalent response timing for the formant transition (Fig. 2B) [$F(1,83) = 1.434$, $p = 0.240$], older nonmusicians demonstrated significantly later response timing relative to younger nonmusicians [$F(1,83) = 4.304$, $p = 0.006$ (Fig. 2C)]. Aging delayed the neural response to the onset (one peak) of sound in both groups

Table 1
Number of males and females in each subject group as well as the mean age and age range for each sex

	Younger				Older			
	Musicians		Nonmusicians		Musicians		Nonmusicians	
	Females	Males	Females	Males	Females	Males	Females	Males
Total	17	9	17	7	15	5	13	4
Mean age	22	23	22	24	55	55	58	57
Age range	18–32	18–30	18–30	21–27	47–65	45–63	45–61	51–65

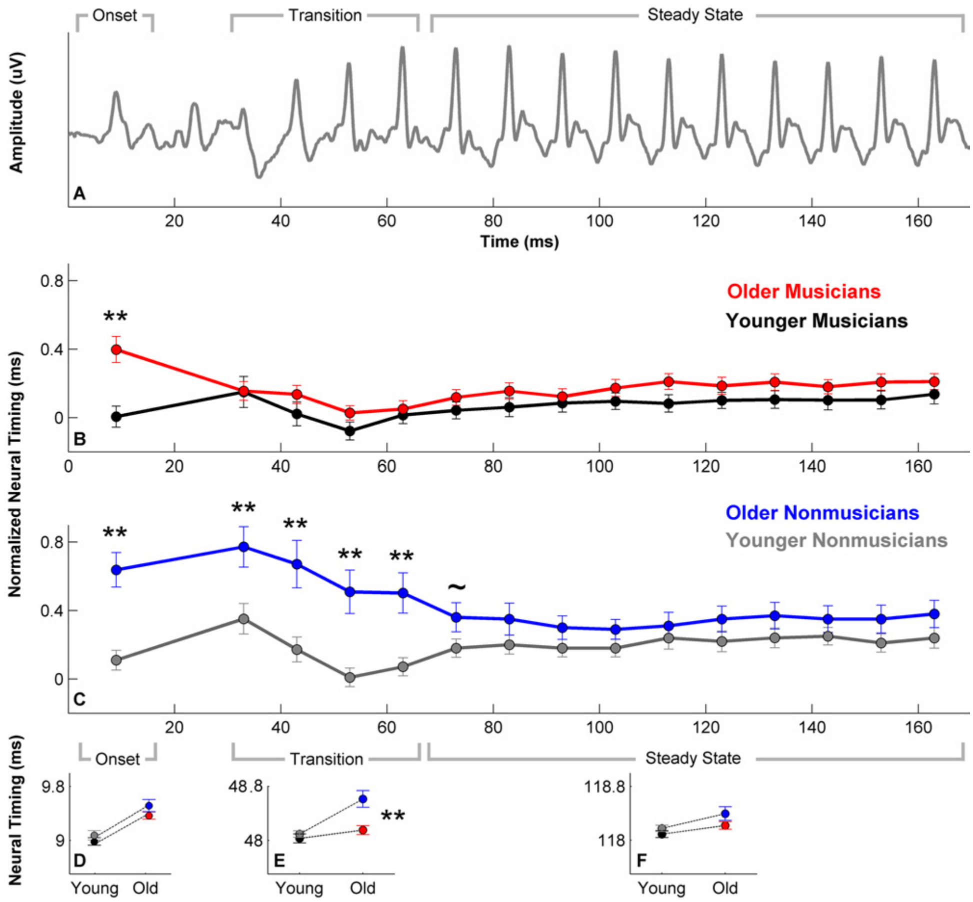

Fig. 2. Musicians show less age-related neural delays than nonmusicians. (A) Average neural response (young musicians) to the speech stimulus [da] divided into 3 regions based on stimulus characteristics: onset, formant transition, and steady-state vowel. (B, C) To facilitate visualization of the data, the peak latencies are normalized. Normalization of the peak latencies was accomplished by subtracting the expected response timing based on stimulus characteristics and neural lag (9 ms for the onset, 33, 43, 53, 63, etc. until 163 ms for the transition and steady state) from each individual's corresponding peak response latency. This resulted in a value between -1 and $+1$ with positive numbers indicating a delay in neural response timing and negative numbers indicating earlier neural response timing relative to the expected response latency. (B) Younger and older musicians have equivalent neural timing except for the onset response. (C) Older nonmusicians show an age-related shift in neural response timing for both the onset and transition. (D–F) Age × Musicianship interaction plots. (D) No Age × Musicianship interaction in the onset. (E) Significant Age × Musicianship interaction in the transition. (F) No Age × Musicianship interaction in the steady state.

equally [Interaction: $F(1,83) = 0.867$, $p = 0.354$; Age: $F(1,83) = 40.045$, $p < 0.001$; Musicianship: $F(1,83) = 5.643$, $p = 0.02$ (Fig. 2D)]. Aging did not affect the neural response to the vowel (70–170 ms, 10 peaks) [Interaction: $F(1,83) = 0.813$, $p = 0.616$; Age: $F(1,83) = 0.757$, $p = 0.669$; Musicianship: $F(1,83) = 1.497$, $p = 0.158$ (Fig. 2F)]. The main effect of musicianship observed for the neural response to the onset and the transition was driven solely by group differences in the older participants [Onset: Younger ($F(1,83) = 1.530$, $p = 0.222$); Older $F(1,83) = 3.739$, $p = 0.061$); Transition: Younger ($F(1,83) = 1.233$, $p = 0.311$); Older: ($F(1,83) = 6.206$, $p = 0.001$)].

4. Discussion

In summary, our results show distinct effects of aging and musicianship on the neural mechanisms responsible for encoding the different components of a stimulus. Specifically, our findings indicate that aging negatively impacts the encoding of noise bursts (i.e. onset) and transient frequency sweeps (i.e. formant transition) but not stable frequency components (i.e. vowel). These outcomes are consistent with the demonstration that stop consonant perception is compromised in older adults, unlike vowel perception, which is minimally affected by age (Ohde and Abou-Khalil, 2001). We also show that although musicians and nonmusicians experience age-related delays in onset timing, the most vulnerable portion of the speech-evoked auditory brainstem response (Anderson et al., 2010; Cunningham et al., 2002), musical experience mitigates the effects of aging on the neural encoding of the formant transition.

That musical experience counteracts age-related delays in subcortical response timing to the formant transition reveals the biologically powerful impact of music on the aging nervous system, raising the question: through which neural mechanisms might musical experience be mediating this effect? Inhibitory processes are potential candidates given their critical role in shaping neural response patterns to temporally dynamic sounds like speech (Caspary et al., 2002; Simon et al. 2004). A reduction in inhibitory receptors occurs with age, fundamentally altering synaptic neurochemistry and compromising the nervous system's ability to represent sound (Caspary et al., 2008). Auditory training in aging rodents bolsters compromised inhibitory processes, essentially reversing age-related deficits (Villers-Sidani et al., 2010). We posit, therefore, that lifelong musical experience is analogous to a long-term auditory training program, in that precise subcortical response timing is sustained through the maintenance of intricately balanced excitatory and inhibitory subcortical neural networks. Although our results speak to the positive effect of musical experience on the aging process, they also hold broader significance: musical experience protects against age-related degradation in neural timing, highlighting the modifiable nature of these declines. These findings should encourage future research into other forms of training that promote neural resilience across the lifespan.

Disclosure statements

None of the authors have any conflict of interest to report that is relative to this manuscript. Northwestern University has no contracts relating to this research through which it or any other organization may stand to gain financially now or in the future. No agreements of authors or their institutions exist that could be seen as involving a financial interest in this work.

The data contained in this manuscript have not been previously published, have not been submitted elsewhere, and will not be submitted elsewhere while under consideration at *Neurobiology of Aging*.

The experimental protocol was reviewed and approved by Northwestern University's Institutional Review Board. All subjects provided written informed consent according to principles set forth by Northwestern University's Institutional Review Board.

All authors have reviewed the contents of the manuscript being submitted, approve of its contents, and validate the accuracy of the data.

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