Hearing Research 302 (2013) 121–131

Contents lists available at SciVerse ScienceDirect

Hearing Research

journal homepage: www.elsevier.com/locate/heares

Research paper

Musicians change their tune: How hearing loss alters the neural code

Alexandra Parbery-Clark [a,b], Samira Anderson [a,b,1], Nina Kraus [a,b,c,d,*]

[a] Auditory Neuroscience Laboratory, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA
[b] Department of Communication Sciences, Northwestern University, Evanston, IL, USA
[c] Neurobiology and Physiology, Northwestern University, Evanston, IL, USA
[d] Otolaryngology, Northwestern University, Evanston, IL, USA

ARTICLE INFO

Article history:
Received 23 December 2012
Received in revised form
19 March 2013
Accepted 22 March 2013
Available online 6 April 2013

ABSTRACT

Individuals with sensorineural hearing loss have difficulty understanding speech, especially in background noise. This deficit remains even when audibility is restored through amplification, suggesting that mechanisms beyond a reduction in peripheral sensitivity contribute to the perceptual difficulties associated with hearing loss. Given that normal-hearing musicians have enhanced auditory perceptual skills, including speech-in-noise perception, coupled with heightened subcortical responses to speech, we aimed to determine whether similar advantages could be observed in middle-aged adults with hearing loss. Results indicate that musicians with hearing loss, despite self-perceptions of average performance for understanding speech in noise, have a greater ability to hear in noise relative to nonmusicians. This is accompanied by more robust subcortical encoding of sound (e.g., stimulus-to-response correlations and response consistency) as well as more resilient neural responses to speech in the presence of background noise (e.g., neural timing). Musicians with hearing loss also demonstrate unique neural signatures of spectral encoding relative to nonmusicians: enhanced neural encoding of the speech-sound's fundamental frequency but not of its upper harmonics. This stands in contrast to previous outcomes in normal-hearing musicians, who have enhanced encoding of the harmonics but not the fundamental frequency. Taken together, our data suggest that although hearing loss modifies a musician's spectral encoding of speech, the musician advantage for perceiving speech in noise persists in a hearing-impaired population by adaptively strengthening underlying neural mechanisms for speech-in-noise perception.

1. Introduction

Daily communication rarely occurs in quiet environments; background noise is often present, degrading the acoustic signal and interfering with the neural transcription of sound (Kujala and Brattico, 2009). While hearing in noise is challenging for everyone, hearing loss exacerbates the negative effects of background noise (Dubno et al., 1984; Helfer and Wilber, 1990). Within the United States alone, approximately 36 million people have a hearing loss (NIDCD, 2012). As such, determining ways to enhance hearing in noise abilities in a hearing-impaired population would have widespread impact on public health; musical training may represent a viable strategy.

Normal-hearing musicians have lifelong hearing advantages in noise (Parbery-Clark et al., 2009b, 2011; Zendel and Alain, 2011) and a greater neural resistance to the deleterious effects of background noise (Parbery-Clark et al., 2009a, 2012b; Strait et al., 2012). We do not know, however, whether these musician advantages are maintained in a population with hearing loss. Sensorineural hearing loss has a profound impact on the auditory system, affecting both peripheral and central structures. For example, auditory deprivation associated with hearing loss can lead to changes in central auditory processing (Aizawa and Eggermont, 2006; Reed et al., 2009; Bureš et al., 2010), compromising auditory perception (Dubno et al., 1984; Blair, 1985; Crandell, 1993) and quality of life (Dalton et al., 2003). Hearing loss also results in tonotopic remapping (Willott, 1991; Harrison et al., 1998; Barsz et al., 2007)

Abbreviations: ABR, auditory brainstem response; dB, decibel; F_0, fundamental frequency; Hz, Hertz; IQ, intelligence quotient; Ms, millisecond; NAL-R, National Acoustic Laboratory-Revised; NIDCD, National Institute on Deafness and other Communication Disorders; RMANOVA, repeated measure analyses of variance; SIN, speech in noise; SNR, signal-to-noise ratio; SSQ, Speech, Spatial and Qualities

* Corresponding author. Auditory Neuroscience Laboratory, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA. Tel.: +1 847 491 3181.
E-mail address: nkraus@northwestern.edu (N. Kraus).
URL: http://www.brainvolts.northwestern.edu

[1] Present address: Department of Hearing and Speech Sciences, University of Maryland, College Park, MD 20742, USA.

0378-5955/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.heares.2013.03.009

and a widening of auditory filters (Tyler et al., 1984; Glasberg and Moore, 1986; Moore, 2007), reducing how spectral information is encoded (Plyler and Ananthanarayan, 2001) and, thus, an individual's ability to analyze the frequency content of sounds (Leek et al., 1987; Summers and Leek, 1994). These changes may account for the speech perception difficulties experienced by hearing-impaired individuals (Dubno et al., 1982; Boothroyd, 1984; Strouse et al., 1998). Since normal-hearing older musicians have heightened auditory perceptual skills as well as enhanced neural encoding of temporal and spectral features of speech (Zendel and Alain, 2011; Parbery-Clark et al., 2012a,b), establishing whether musical training in a hearing-impaired population enhances the perception and neural encoding of speech in noise has important rehabilitative and clinical implications.

Here, we asked whether musicians' advantages for the perception and neural encoding of speech in noise are maintained with hearing loss. To address this question, we assessed hearing-in-noise abilities with standardized clinical tests and self-report, in addition to speech-evoked auditory brainstem responses in quiet and noisy backgrounds. We focused our analyses on neural timing, spectral encoding, and the precision of neural encoding (i.e., neural response fidelity and consistency) – all measures that have previously distinguished normal hearing children, young adult and middle-aged musicians from their nonmusician counterparts (Parbery-Clark et al., 2009a, 2012a,b; Strait et al., 2012) and that are known to decline with age and hearing loss (Clinard et al., 2010; Vander Werff and Burns, 2011; Anderson et al., 2012). We were especially interested in determining whether hearing loss diminishes known musician biological advantages or, alternatively, whether new musician neural signatures emerge in the face of hearing loss. We hypothesized that hearing-impaired musicians maintain hearing benefits in noise over nonmusicians and that these advantages are undergirded by more resilient neural encoding of speech.

2. Methods

2.1. Participants

Thirty-four middle-aged adults with mild or moderate sensorineural hearing loss (Fig. 1) participated (45–65 years, mean age 58 ± 4 years). Seventeen subjects were categorized as musicians, having started musical training before the age of nine and were engaged in musical activities a minimum of three times a week since then. Seventeen subjects were categorized as nonmusicians, with 11 having had no musical training and 6 having fewer than 5 years of accrued musical experience; (Table 1).

Participants had no history of neurological or learning disorders nor reported a history of chemotherapy or ototoxic medication, major surgeries or head trauma. Octave frequencies between 0.125 and 12.5 kHz were tested including 3 and 6 kHz. All participants had symmetric pure-tone thresholds (defined as $\leq$15 dB difference at two or more frequencies between ears). All participants had normal click-evoked auditory brainstem responses (defined as a wave V latency of $\leq$6.8 ms at 80 dB SPL presented at a rate of 31.25 Hz). In addition, all participants were native English speakers and had normal non-verbal IQ, as assessed by the Abbreviated Wechsler's Adult Scale of Intelligence's matrix reasoning subtest (Wechsler, 1999). All experimental procedures were approved by the Northwestern University Institutional Review Board; all participants provided informed written consent.

Musician and nonmusician groups were matched on hearing thresholds (0.125–12.5 kHz including 3 and 6 kHz; $F_{(1,33)} = 0.733$; $p = 0.743$; Fig. 1). No participant reported sudden hearing loss; 7 musicians and 4 nonmusicians indicated that they had bilateral tinnitus. No participants reported a history of hearing aid usage. Groups were equated on measures of age, click wave V latency and IQ (all $P > 0.4$; Table 2).

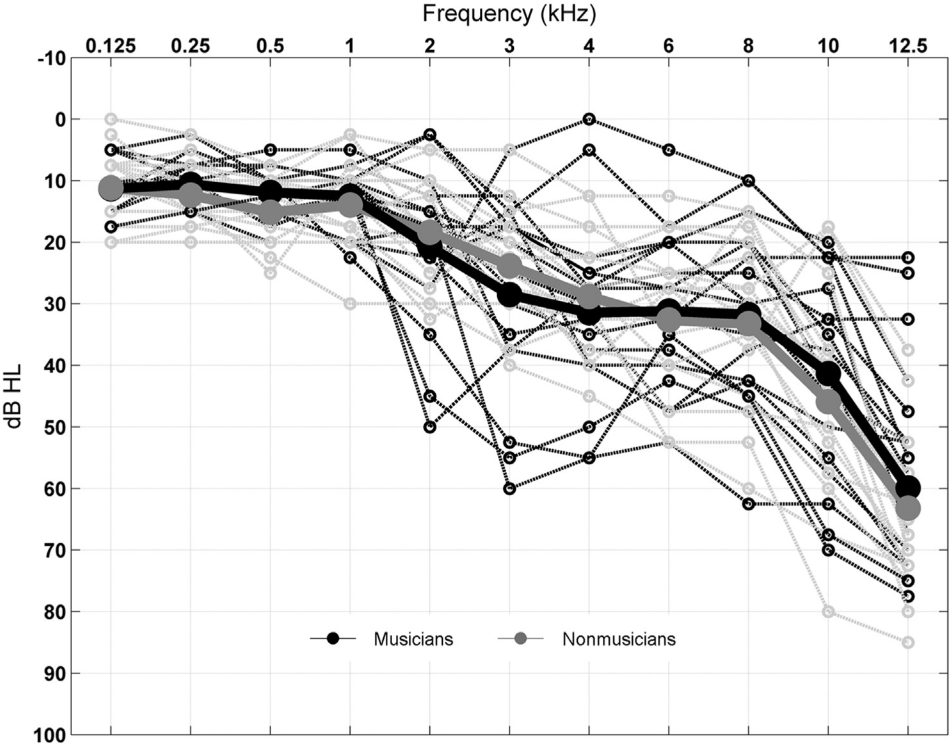

Fig. 1. Audiometric profiles. Mean pure-tone thresholds (average of right and left ears) for musicians (black) and nonmusician (grey) from 0.125 to 12.5 kHz. Dashed lines indicate individual data. Musician and nonmusician groups demonstrated equal hearing sensitivity ($F_{(1,33)} = 0.733$; $p = 0.743$).