Hearing Research 344 (2017) 275–283

Contents lists available at ScienceDirect

Hearing Research

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

Research Paper

Musicianship enhances ipsilateral and contralateral efferent gain control to the cochlea

Gavin M. Bidelman [a, b, *], Amy D. Schneider [a], Victoria R. Heitzmann [a], Shaum P. Bhagat [a]

[a] School of Communication Sciences & Disorders, University of Memphis, Memphis, TN, USA
[b] Institute for Intelligent Systems, University of Memphis, Memphis, TN, USA

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form
29 November 2016
Accepted 8 December 2016
Available online 11 December 2016

Keywords:
Hearing
Noise-induced hearing loss
Experience-dependent plasticity
Musical training
Otoacoustic emissions (OAEs)
Medial olivocochlear (MOC) efferents

ABSTRACT

Human hearing sensitivity is easily compromised with overexposure to excessively loud sounds, leading to permanent hearing damage. Consequently, finding activities and/or experiential factors that distinguish "tender" from "tough" ears (i.e., acoustic vulnerability) would be important for identifying people at higher risk for hearing damage. To regulate sound transmission and protect the inner ear against acoustic trauma, the auditory system modulates gain control to the cochlea via biological feedback of the medial olivocochlear (MOC) efferents, a neuronal pathway linking the lower brainstem and cochlear outer hair cells. We hypothesized that a salient form of auditory experience shown to have pervasive neuroplastic benefits, namely musical training, might act to fortify hearing through tonic engagement of these reflexive pathways. By measuring MOC efferent feedback via otoacoustic emissions (cochlear emitted sounds), we show that dynamic ipsilateral and contralateral cochlear gain control is enhanced in musically-trained individuals. Across all participants, MOC strength was correlated with the years of listeners' training suggested that efferent gain control is experience dependent. Our data provide new evidence that intensive listening experience(s) (e.g., musicianship) can strengthen the ipsi/contralateral MOC efferent system and sound regulation to the inner ear. Implications for reducing acoustic vulnerability to damaging sounds are discussed.

1. Introduction

Intense acoustic environments can be hazardous to human hearing as overexposure to excessively loud sounds can result in permanent noise-induced hearing loss (NIHL). NIHL is second only to age-related hearing impairments (Rabinowitz, 2000) and accounts for more than $1 billion in medical costs in the USA (USDoVA, 2005). Indeed, it is estimated that ~26 million people suffer from some form of NIHL (NIH/NIDCD, 2008) and there is growing concern that recreational noise exposure (e.g., personal music players) may be increasing NIHL prevalence among the general population (Levey et al., 2012; WHO, 2015). Problematically, there is considerable inter-subject variability in vulnerability to noise exposure and acquiring cochlear injury due to excessively loud sounds (Cody and Robertson, 1983; Patuzzi and Thompson, 1991). Furthermore, transient (i.e., temporary) hearing losses due to less traumatic noise exposures do not predict progression to permanent acoustic injury (Ward, 1965). This variability has led to the speculation that some listeners might have "tough" ears that are more resilient to noise damage, while others have "tender" ears more sensitive to acoustic insult (Maison and Liberman, 2000). Consequently, identifying listening activities and/or experiential factors that predict or offset acoustic vulnerability (i.e., distinguish "tender" from "tough ears") could be important in identifying people at higher risk for developing NIHL and preventing certain recreational hearing damage.

In this regard, musical training has been shown to have profound impact on auditory skills, improving not only basic perceptual acuity for speech sounds but also the brain's ability to extract important communication signals from the auditory scene (for reviews, see Alain et al., 2014; Moreno and Bidelman, 2014; Strait and Kraus, 2014). Functional changes secondary to musical training have been observed in all stages of the auditory system from cerebral cortex (Bidelman and Alain, 2015; Bidelman et al., 2014b; Schneider et al., 2002; Shahin et al., 2003) to the auditory brainstem (Bidelman et al., 2011, 2014b; Musacchia et al., 2007;

* Corresponding author. School of Communication Sciences & Disorders, University of Memphis, 4055 North Park Loop, Memphis, TN 38152, USA.
E-mail address: g.bidelman@memphis.edu (G.M. Bidelman).

http://dx.doi.org/10.1016/j.heares.2016.12.001
0378-5955/

Wong et al., 2007), and as peripheral as the human cochlea (Bidelman et al., 2014a, 2016). Given the pervasiveness of musical engagement to benefit a wide variety of auditory (and non-auditory) skills, musicians are widely considered an ideal model for understanding the brain's capacity for neuroplasticity (Bidelman, 2016; Herholz and Zatorre, 2012; Kraus and Chandrasekaran, 2010; Moreno and Bidelman, 2014; Zatorre and McGill, 2005).

While musicianship has been shown to positively enhance certain aspects of auditory function, presumably, long-term music training could also produce detrimental consequences to hearing. Notably, musicians experience sound levels (>90–100 dBA) (Gopal et al., 2013; Møllerløkken et al., 2013; Royster et al., 1991; Schmidt et al., 2011) that regularly exceed recommended daily noise exposure levels (i.e., 85 dBA) (NIOSH, 1998). While most studies have focused on musical ensemble environments, excessive noise is also apparent during individual practice, when sound levels are exacerbated in smaller acoustic spaces (Poissant et al., 2012). Consequently, there is increasing concern that excessive exposure to intense sound levels during music rehearsal may be increasing the prevalence of noise-related hearing impairments among people who engage in music performance (Henning and Bobholz, 2016; Phillips et al., 2010). On the contrary, enduring higher sound levels over time may act to fortify (rather than impair) hearing through tonic engagement of reflexive pathways that help regulate sound transmission and protect the inner ear against overexposure (Brashears et al., 2003; Maison and Liberman, 2000). This raises the intriguing possibility that musical training might help strengthen the ear and actually protect against some forms of noise-related hearing damage. To our knowledge, the competing hypotheses of music as a catalyst vs. a deterrent to NIHL have not been fully tested.

A possible biological mechanism thought to protect the cochlea against acoustic trauma is the medial olivocochlear (MOC) efferent pathway (Patuzzi and Thompson, 1991). MOC neurons originate in the lower brainstem and terminate back in the auditory periphery where they innervate the cochlear outer hair cells. The role of the MOC efferents in human hearing is still debated. Nevertheless, several studies implicate this pathway in important aspects of real-world listening including (among other functions) playing an “antimasking” role (Bidelman and Bhagat, 2015; Guinan, 2006) to improve signal extraction in noise (Bidelman and Bhagat, 2015; Micheyl and Collet, 1996) and auditory learning (de Boer and Thornton, 2008). Additionally, given the MOC system is capable of regulating the gain of cochlear amplification (Guinan, 2006), it is also thought to play an important role in controlling input sound level and preventing acoustic damage to the ear (Kujawa and Liberman, 1997; Maison and Liberman, 2000). The critical importance of MOC feedback in protecting against acoustic vulnerability is evident in animal studies, which demonstrate that the integrity of this efferent fiber bundle is necessary to reduce temporary and permanent noise-induced threshold shifts (Kujawa and Liberman, 1997; Patuzzi and Thompson, 1991; Rajan, 1992; Zheng et al., 1997) and prevent synaptopathy (Maison et al., 2013) of the cochlear nerve fibers following traumatic acoustic exposure.

In humans, MOC activation can be assayed noninvasively via otoacoustic emissions (OAEs). OAEs are bioacoustic (cochlear emitted) sounds measured in the ear canal with highly sensitive microphones that reflect cochlear health and peripheral auditory processing (Kemp et al., 1990; Probst et al., 1991). Activation of the MOC bundle dampens outer hair cell electromotility through inhibition, resulting in measurable changes in cochlear emissions (Bhagat and Kilgore, 2014; Bidelman and Bhagat, 2015; Guinan, 2006; Philibert et al., 1998). Germane to our investigation, several lines of evidence suggest that MOC function might be sensitive to the experience-dependent effects of musicianship. Relative to their nonmusician peers, musically trained listeners experience less loudness adaptation (Micheyl et al., 1995) concurrent with a greater reduction in OAE amplitudes when sound is delivered to the contralateral ear (Brashears et al., 2003; Micheyl et al., 1995, 1997; Perrot et al., 1999)—both proxy measures of MOC activation. Moreover, we have recently shown that musicianship sharpens human cochlear tuning as assessed via OAE tuning curves (Bidelman et al., 2016). Presumably, these musician enhancements in cochlear processing could develop via enhanced MOC feedback, strengthened through protracted musical training and intensive interaction with complex auditory signals (Bidelman et al., 2016; Brashears et al., 2003; Micheyl et al., 1997).

Here, we extend this previous work to test the hypothesis that long-term music engagement can strengthen the temporal dynamics of ipsi- and contra-lateral MOC feedback to the ear. Experimental noise exposures are possible in animal studies (Maison et al., 2000), but is no longer ethically viable in human listeners given the potential risk of inducing permanent hearing loss (Maison et al., 2013). Thus, our general approach used a combination of perceptual and noninvasive physiological assays to measure hearing sensitivity and auditory function in musically trained (~10 years experience) and untrained listeners that are known to index acoustic vulnerability (Maison and Liberman, 2000). We estimated the strength of listeners' MOC efferent feedback in both the ipsilateral (crossed) and contralateral (uncrossed) olivocochlear pathways by measuring the adaptation time courses of distortion product (DP) OAEs (ipsilateral assay) and contralateral suppression (contralateral assay). OAE responses provide a non-invasive assay of cochlear health and are routinely used in audiological practice to detect noise-related impairments (Attias et al., 2001). Moreover, they serve as an early indicator of noise damage as changes in these cochlear responses precede the development of music-induced hearing deficits (Bhagat and Davis, 2008). Stronger ipsilateral and contralateral efferent cochlear gain control in musicians' OAEs would be consistent with the notion that musicianship might reduce noise vulnerability and overall susceptibility to acoustic trauma.

Upon energizing the cochlea, emissions typically adapt in amplitude over ~100–200 ms as neuronal MOC efferent feedback is engaged and cochlear amplification is attenuated (Backus and Guinan, 2006; Maison and Liberman, 2000; Warren and Liberman, 1989). Importantly, animal studies have shown that the magnitude of this DPOAE adaptation can be used to predict individual vulnerability to acoustic trauma (Maison and Liberman, 2000) and thus, a means to assess hearing risk. To date, this approach has only been successful in animal models (Maison and Liberman, 2000). By adapting this methodology for human application, we show that musicians have stronger MOC-related cochlear feedback than their nonmusician peers that varies with the length of their auditory training (i.e., experience-dependent manner). Our findings imply that musicianship might help reduce acoustic vulnerability to potentially damaging sounds by “toughening” the natural intensity regulation to the cochlea.

2. Materials & methods

2.1. Participants

Twenty young adults (age range: 18–31 years) participated in the experiment: 12 musicians (4 males, 8 females) and 8 nonmusicians (5 males, 3 females). Consistent with inclusion criteria and the definitions of “musician” and “nonmusician” used in previous reports (Bidelman et al., 2014a, 2016), musicians (Ms) were amateur instrumentalists who had received $\geq$ 9 years of continuous