

Use it or Lose it: Hearing Abilities are Preserved in Older Musicians

Published April 17th, 2014

Claude Alain, PhD

Benjamin Rich Zendel, PhD

ABSTRACT

As adults grow older, they often experience difficulty understanding what a person is saying in the presence of other sounds (e.g., television, music, other people talking). Such age-related declines in listening are a major challenge for hearing science and medicine because of their wide prevalence. Furthermore, hearing aid technologies have so far been unable to effectively alleviate this problem. Here, we review studies that have investigated the role of musical training as a mean to mitigate age-related decline in difficulties understanding speech in noise. This review of literature shows that musicians exhibit exceptional auditory skills that allow them to cope with age-related hearing loss better than non-musicians. In particular, continuous engagement in musical activities throughout adulthood is associated with slower age-related decline in understanding speech in noise. Neuroscience research has shown that musical training enhances central auditory processing, which can compensate for peripheral hearing loss. The benefit of musical training on the aging auditory brain is exciting and it opens new avenues for developing new remediation programs and improving current rehabilitation protocols aimed at helping older adults in noisy environments.

RÉSUMÉ

Comme les adultes vieillissent, ils éprouvent souvent des difficultés à comprendre ce qu'une personne dit en présence d'autres sons (par exemple, la télévision, la musique, d'autres personnes qui discutent). Ces baisses liées à l'âge dans l'écoute sont un défi majeur pour la science et la médecine en raison de leur grande prévalence. En outre, les technologies d'aides auditives ont été jusqu'à présent incapable de lutter efficacement contre ce problème. Ici, nous passons en revue les études qui ont examiné le rôle de la formation musicale comme un moyen d'atténuer le déclin lié à l'âge dans la difficulté à comprendre la parole dans le bruit. Cette revue de la littérature montre que les musiciens présentent des capacités auditives exceptionnelles qui leur permettent de faire face à la perte d'audition liée à l'âge mieux que les non-musiciens. En particulier, poursuivre l'engagement d'activités musicales à l'âge adulte est associé avec une diminution des problèmes de compréhension de la parole dans le bruit. La recherche en neurosciences a montré que la formation musicale améliore le traitement auditif central, qui compense pour la perte auditive périphérique. Cette découverte que la formation musicale ralentit le déclin du traitement auditif des personnes âgées est excitante et ouvre de nouvelles avenues de recherches pour le développement de nouveaux programmes d'entraînement auditif et l'amélioration des protocoles de réhabilitation actuels visant à aider les personnes âgées à comprendre les sons de la parole dans des environnements bruyants.

Introduction

Canadians are living longer than ever. The average Canadian can expect to live for over 80 years. This increased life expectancy has led to an unprecedented growth in our population of senior citizens. In fact, by 2036, 25% of the total population (9.2 million people) will be over the age of 65. Unfortunately, this success has led to an increase in age-related medical conditions, including age-related hearing loss (ARHL), which is nearly universal in older adults. Symptoms of ARHL often begin in the fourth decade of life increasing in severity with increasing age. There is currently no cure, and many suffer in silence.

One of the most common symptoms of ARHL is a decrease in the ability to understand speech, especially in noisy situations. The inability to understand speech in noisy situations is often considered one of the most debilitating aspects of aging because it contributes to reduced interpersonal relations, confusion, financial insecurity, and a poorer quality of life.^{1,2} These issues can further lead to depression and cognitive decline.³ Accordingly, finding ways to mitigate age-related decline in the ability to understand speech in noise is of utmost importance.

In noisy situations, such as cocktail parties, social gatherings and sporting events, understanding speech depends on how well the brain can extract and process speech signals from background noise. Unfortunately, simply “turning up the volume” in a hearing aid will not improve understanding as it depends on both attention and memory processes in addition to hearing sensitivity. Understanding speech is more than detecting sounds and it highly depends on the listeners’ ability to decipher the surrounding sounds in meaningful ways.

Speech comprehension in noisy environments is constrained by our capacity to hold critical information in working memory while keeping irrelevant information (external stimuli or internal thought) from intruding. For effective speech comprehension, listeners must be able to group together sound elements coming from one source (i.e., the words from one speaker) and segregate those from other sources (e.g., the words from another speaker). The process of perceptually organizing our auditory surroundings is known as auditory scene analysis.⁴ It depends on a coordinated effort of both bottom-up processes that group sounds together based on acoustic features and top-down schema-driven processes that guide selective attention. Once the auditory scene has been partitioned into different sound objects, a selection process allows an individual to focus on a particular object and switch their attention from one representation to another. Importantly, both bottom-up (i.e., stimulus salience) and top-down demands (i.e., internal goals) determine which sound(s) in our surroundings are selectively attended.^{5,6}

The importance of cognitive functions in ARHL is highlighted by research that demonstrates a greater disadvantage in understanding speech in noise by older adults when the background noise is meaningful (speech) as opposed to meaningless (e.g., foreign speech or speech played backwards) compared to younger adults.^{7,8} This finding cannot be explained simply by age-related physical changes in the outer, middle, and inner ear. Recognizing the contributions of sensory and cognitive factors to speech understanding can expand treatment possibilities for ARHL beyond just using hearing aids that only amplify and modulate the incoming acoustic signal. It is now well established that targeted training and lifestyle factors can alter neural structures and functions.⁹ By extension, one can imagine that hearing abilities can be improved by targeting plasticity in large neural networks using musical training. As a matter of fact, the last decade has seen a surge of interest in assessing the possibility of using musical training to slow or even reverse age-related declines in auditory perception and cognition.

What Is So Special About Musical Training?

Playing a musical instrument is a cognitively complex task that can take thousands of hours to master. It not only engages the auditory system, but also involves auditory-motor coordination, audio-visual and tactile integration, planning, attention, working memory, long-term memory and learning of the implicit and explicit “rules” that govern the musical system. It is therefore not surprising that the benefits of musical training are not limited to musical performance alone but can also transfer to other auditory and cognitive domains.^{10,11} For instance, children who received piano or vocal lessons showed greater gain in intellectual quotient (IQ) compared to children who were enrolled in drama classes.¹⁰ Additionally, children that received music lessons had improved auditory abilities,¹² and enhanced brain volume¹³ compared to a control group. Critically, these studies utilized random assignment, thus post-training differences between the groups were caused by the music lessons.

Other studies have investigated the benefits of lifelong musicianship on cognitive abilities. For instance, musicians aged between 45 and 65 performed better than age-matched controls on an auditory working memory task, but not a visual working memory task.¹⁴ Older adults (aged 60 to 83) with at least 10 years of musical experience performed better on the nonverbal memory task, naming visual objects (i.e., Boston naming test), and measures of speeded visual information processing (i.e., Trails A and B).¹⁵ In a subsequent study, that controlled for general physical (exercise) activity level, Hanna-Pladdy and Gajewski¹⁶ demonstrated that older musicians scored higher on tests of phonemic fluency, verbal working memory, verbal immediate recall, visuospatial judgment, and motor dexterity compare to older non-musicians. Interestingly, Sluming et al.¹⁷ found that gray matter density in the left inferior frontal gyrus was preserved in older professional (orchestral) musicians, while age-related volume reductions were observed in non-musicians.

Using structural equation modeling, Anderson et al.¹⁸ showed that central auditory processing and cognitive function predicted a significant proportion of variance in the ability to understand speech in noisy environments. More importantly, past musical experience modulated the relative contributions of cognitive ability and lifestyle factors (e.g., physically and intellectually engaging activity) in the ability to understand speech in noisy environments for older adults (aged 55 to 79). These findings suggest that musical training might create a cognitive reserve, which can delay age-related cognitive decline.¹⁹ These studies also highlight the unique nature of musical training, and its ability to transfer cognitive and perceptual benefits to domains beyond musical performance.

Musicians Maintain Listening Skills in Old Age

There is increasing evidence that lifelong musicianship may slow age-related declines in auditory processing abilities including speech in noise comprehension.^{14,20} Zendel and Alain²⁰ measured auditory processing abilities in lifelong musicians ($N = 74$) and non-musicians ($N = 89$), aged between 18 and 91. Musicians were defined as individuals who began musical training prior to age 16, continued practicing music until the time of testing, and had an equivalent of at least six years of formal music lessons; non-musicians in the study did not play a musical instrument. As expected, hearing sensitivity, assessed via pure tone thresholds, declined with age but more importantly, this decline was similar for both musicians and non-musicians. At the same time, musicians had superior abilities for detecting inharmonicity and this advantage was stable throughout their lifespan. In addition, musicians had lower gap-detection and speech-in-noise (QuickSIN) thresholds, and the benefit increased with age. Through musical training, a 70-year-old

musician can understand speech-in-noise as well as a 50-year-old non-musician. Similar findings were reported by Parbery-Clark et al.¹⁴ who also found that older musicians had lower thresholds on the Quick SIN, the hearing in noise test (HINT), and the word in noise (WIN) test compared to non-musicians. Together these results imply that musical training and continued practice of a musical instrument may reduce the impact of age-related decline in listening skills. It is likely that musical training provides musicians (professional and amateur alike) with strategies that allow them to more easily extract task-relevant acoustic information, while at the same time tune out task-irrelevant sounds. We proposed that musical training develops a cognitive reserve that allows older musicians to maintain auditory-cognitive skills (i.e., listening abilities) in advanced age. Here, the term “cognitive reserve” refers to the brain’s ability to optimize performance on cognitive tasks (e.g., IQ test) despite age-related neuropathological loss.

How Does Musical Training Mitigate Against Age-Related Changes in Auditory Cognition

There is growing agreement that age-related changes in the peripheral and central auditory system reduce the precision of the signal being delivered to higher auditory cognitive systems. Musical training and continued musicianship through adulthood may help preserve the early bottom-up processing of sound so that older musicians have a higher fidelity input into the higher auditory cognitive systems. Alternatively, older musicians may be better at engaging compensatory strategies to overcome impoverished sensory processing (top-down processing).

These two possibilities are not mutually exclusive and neurophysiological evidence supports both possibilities. Recent work suggests that older musicians have an improved efficiency and/or precision in how their brains encode and process speech formants in the early auditory pathway. For example, there was less age-related neural delay in the auditory brainstem response (ABR) to consonant-vowel speech sounds in older musicians compared to age-matched non-musicians.²¹ Neuroplastic changes in ABRs may be mediated by top-down processes via the cortico-fugal pathway and/or reflect bottom-up shaping of the neuronal responses with repeated exposure.²²

To further understand how lifelong musicianship interacts with cognitive auditory processes (i.e., top-down), we investigated the impact of attention on the neural processes related to separating concurrent sounds.²³ Again, we found that both older and younger musicians were better able to segregate a mistuned harmonic as a separate sound object compared to their age-matched non-musician counterparts. Neurophysiological data revealed that in older musicians this improvement was related to enhanced attention-related (i.e., top-down) processing of the mistuned harmonic. In younger musicians, the benefit was related to both attention-independent (i.e., bottom-up) and attention-related processing. Further support for this finding comes from a second study where we investigated how attention impacts the electrophysiological response of the auditory cortex to a harmonically complex sound.²⁴ We found an enhanced attention-dependant response to harmonically complex stimuli in the right auditory cortex of older musicians, compared to younger musicians, and older and younger non-musicians. These findings suggest that the lifelong benefit of musical training may be related to volitional, attention-dependent cognitive processing of acoustic information. It further suggests that older musicians may be using top-down processing to help overcome declining bottom-up processing.

Training Vs. Pre-existing Conditions

The cross-sectional studies reviewed above indicate that listening abilities are enhanced in older musicians compared to non-musicians. There is no doubt that these studies encourage the use of

music-based remediation programs, however it is critical to note that they have focused exclusively on highly-trained musicians with decades of experience. Hence, it is also possible that lifelong musicians became and stayed musicians throughout their life because of pre-existing auditory advantages. Ultimately, the efficacy of using music training to improve listening in older adults will depend on a randomized control study that demonstrates a causal relationship between training and auditory perceptual benefits in older adults.

While cross-sectional studies do not allow for the determination of causality, correlations within the data can suggest the direction of causality. For example, the degree of a musician's auditory perceptual and neurophysiological enhancements is often positively associated with the number of years of training and negatively associated with the age at which training was initiated.^{20,25} These types of correspondence suggest that the benefits observed in musicians stem from neuroplastic effects that are modulated by the amount of training and/or influenced during a sensitive period in childhood. While care must be exercised when drawing causation from correlational data, these findings are further corroborated by randomized, longitudinal training studies that have demonstrated causal, experience-dependent effects of musical training at both behavioral and neurophysiological levels. However these studies have focused on children and young adults.^{12,26}

Critical questions also arise as to what factors in a music-based remediation program might provide the greatest auditory benefits. It is possible that successful music-induced neural and behavioural effects documented in young adults and children^{12,26} may not yield the same degree of benefit in "less" plastic brains of older adults.²⁷ One might expect musical training in childhood to induce long-lasting neurophysiological changes that would provide older adults with an advantage in noisy listening environments. At the same time, we can also posit that if the musical training begins later in life, the balance will shift toward enhancing listening skills, which can then be used to segregate and attend to one conversation in noisy settings. While leisurely listening to music may promote health and well-being in older individuals [e.g., mediating stress, reducing heart and respiratory activity,²⁸ it is unlikely to have an efficacious impact on real-world auditory abilities. For musical training to transfer and benefit non-musical functions (e.g., understanding speech in noise, auditory scene analysis), it is likely that an individual must be engaged with fairly intense instructions to promote hierarchical cognitive processing via integration of multiple perceptual modalities (i.e., auditory, visual, tactile, and proprioceptive). Indeed, the beneficial effects of musicianship have been attributed to this complex processing and not simply attentive listening.²⁹ Moreover, musical training exerts plastic effects at both microscopic (i.e., localized) and macroscopic (i.e., network) levels of the brain.³⁰ This distributed plasticity may be responsible for musicians' enhanced cognitive abilities, including working memory, attention, and executive processes.³¹⁻³³ Thus, in addition to examining the long-term retention of music-related benefits and providing cognitive reserve, future work will need to assess the duration for which music regimens must be applied before yielding a lasting change in behaviour. It is likely that the benefits of music training will vary in an age-dependent manner.

Nevertheless, recent work suggests that the auditory neuroplasticity afforded by musical training in childhood might be retained into adulthood, even after cessation of music lessons and practice in early adolescence.³⁴ Thus, even short-term music lessons may promote positive functional changes in auditory processing that persist well beyond the termination of training. However, these benefits may also be related to sensitive periods in childhood. Accordingly, future work is needed to fully validate short-term music-based training programs aimed to counteract age-related declines in

auditory-based communication problems in older adults.

Concluding Remarks

Older adults have difficulty processing rapid temporal fluctuations and segregating concurrent objects in the auditory environment. These perceptual deficits are thought to contribute to their difficulties in auditory scene analysis, including perceiving speech-in-noise and parsing acoustic information into multiple streams. The presence of these deficits in the absence of measurable hearing loss indicates that some of the perceptual issues faced by older adults probably emerge as a result of changes to central (i.e., non-cochlear) auditory mechanisms. Studies indicate that musical training positively modifies central brain and behavioural mechanisms to provide robust, long-lasting improvements to auditory abilities across the lifespan. Intense and engaging short-term musical training programs may offer potential benefit to improve or at least offset the difficulties in complex listening experienced by older adults.

Acknowledgements

We thank Jeffrey Wong and Stephen Arnott for their suggestions in earlier versions of this manuscript.

References

1. Betlejewski S. [Age connected hearing disorders (presbycusis) as a social problem]. *Otolaryngol Pol* 2006;60(6):883–6.
2. Genther DJ, et al., Association of hearing loss with hospitalization and burden of disease in older adults. *JAMA* 2013;309(22):2322–4.
3. Lin FR, et al., Hearing loss and cognitive decline in older adults. *JAMA Intern Med* 2013;1–7.
4. Bregman AS. Auditory scene analysis: the perceptual organization of sounds. London, England: The MIT Press; 1990.
5. Alain C and Arnott SR, Selectively attending to auditory objects. *Front Biosci* 2000;5:D202–12.
6. Alain C. and Bernstein LJ. From sounds to meaning: The role of attention during auditory scene analysis. *Curr Opin Otolaryngol Head Neck Surg* 2008;16:485–89.
7. Tun PA, O'Kane G and Wingfield A. Distraction by competing speech in young and older adult listeners. *Psychol Aging* 2002;17(3):453–67.
8. Rossi-Katz J. and Arehart KH. Message and talker identification in older adults: effects of task, distinctiveness of the talkers' voices, and meaningfulness of the competing message. *J Speech Lang Hear Res* 2009;52(2):435–53.
9. Scarmeas N and Stern Y. Cognitive reserve and lifestyle. *J Clin Exp Neuropsychol* 2003;25(5):625–33.
10. Schellenberg EG. Music lessons enhance IQ. *Psychol Sci*, 2004;15(8):511–4.
11. Schellenberg EG. Examining the association between music lessons and intelligence. *Br J Psychol* 2011;102(3):283–302.
12. Fujioka T, et al. One year of musical training affects development of auditory cortical-evoked fields in young children. *Brain* 2006;129(Pt 10):2593–608.
13. Schlaug G. The brain of musicians. A model for functional and structural adaptation. *Ann N Y Acad Sci* 2001;930:281–99.
14. Parbery-Clark A, et al., Musical experience and the aging auditory system: implications for cognitive abilities and hearing speech in noise. *PLoS One* 2011;6(5):e18082.
15. Hanna-Pladdy B and MacKay A. The relation between instrumental musical activity and cognitive aging. *Neuropsychology* 2011;25(3):378–86.
16. Hanna-Pladdy B. and Gajewski B. Recent and past musical activity predicts cognitive aging

- variability: direct comparison with general lifestyle activities. *Front Hum Neurosci*, 2012;6:198.
17. Sluming V, et al. Voxel-based morphometry reveals increased gray matter density in Broca's area in male symphony orchestra musicians. *Neuroimage*, 2002;17(3):1613–22.
 18. Anderson S, et al., A dynamic auditory-cognitive system supports speech-in-noise perception in older adults. *Hear Res* 2013.
 19. Amer T, et al., Do older professional musicians have cognitive advantages? *PLoS One*, 2013;8(8):e71630.
 20. Zendel BR and Alain C. Musicians experience less age-related decline in central auditory processing. *Psychol Aging* 2012;27(2):410–7.
 21. Parbery-Clark A, et al., Musical experience offsets age-related delays in neural timing. *Neurobiol Aging* 2012;33(7):1483 e1–4.
 22. de Boer J and Thornton AR. Neural correlates of perceptual learning in the auditory brainstem: efferent activity predicts and reflects improvement at a speech-in-noise discrimination task. *J Neurosci* 2008;28(19):4929–37.
 23. Zendel BR and Alain C The influence of lifelong musicianship on neurophysiological measures of concurrent sound segregation. *J Cog Neurosci* 2013;25(4):503–16.
 24. Zendel BR and Alain C. Enhanced attention-dependent activity in the auditory cortex of older musicians. *Neurobiol Aging* 2014;35(1):55–63.
 25. Parbery-Clark A, et al., Musician enhancement for speech-in-noise. *Ear Hear* 2009;30(6):653–61.
 26. Hyde KL, et al., Musical training shapes structural brain development. *J Neurosci* 2009;29(10):3019–25.
 27. Stiles J. Neural plasticity and cognitive development. *Dev Neuropsychol*, 2000;18(2):237–72.
 28. Bernardi L, Porta C, and Sleight P. Cardiovascular, cerebrovascular, and respiratory changes induced by different types of music in musicians and non-musicians: the importance of silence. *Heart* 2006;92(4):445–52.
 29. Lappe C, et al. Cortical plasticity induced by short-term unimodal and multimodal musical training. *J Neurosci* 2008;28(39):9632–9.
 30. Wan CY and Schlaug G Music making as a tool for promoting brain plasticity across the life span. *Neuroscientist* 2010;16(5):566–77.
 31. Pallesen KJ, et al. Cognitive control in auditory working memory is enhanced in musicians. *PLoS One* 2010;5(6):e11120.
 32. Bidelman GM, Hutka S, and Moreno S. Tone language speakers and musicians share enhanced perceptual and cognitive abilities for musical pitch: evidence for bidirectionality between the domains of language and music. *PLoS One* 2013;8(4):e60676.
 33. Bialystok E. and Depape AM. Musical expertise, bilingualism, and executive functioning. *J Exp Psychol Hum Percept Perform* 2009;35(2):565–74.
 34. Skoe E. and Kraus N. A little goes a long way: how the adult brain is shaped by musical training in childhood. *J Neurosci* 2012;32(34):11507–10.