Musicians, Hearing Care Professionals, and Neuroscientists

Intriguing findings regarding brain plasticity and music training

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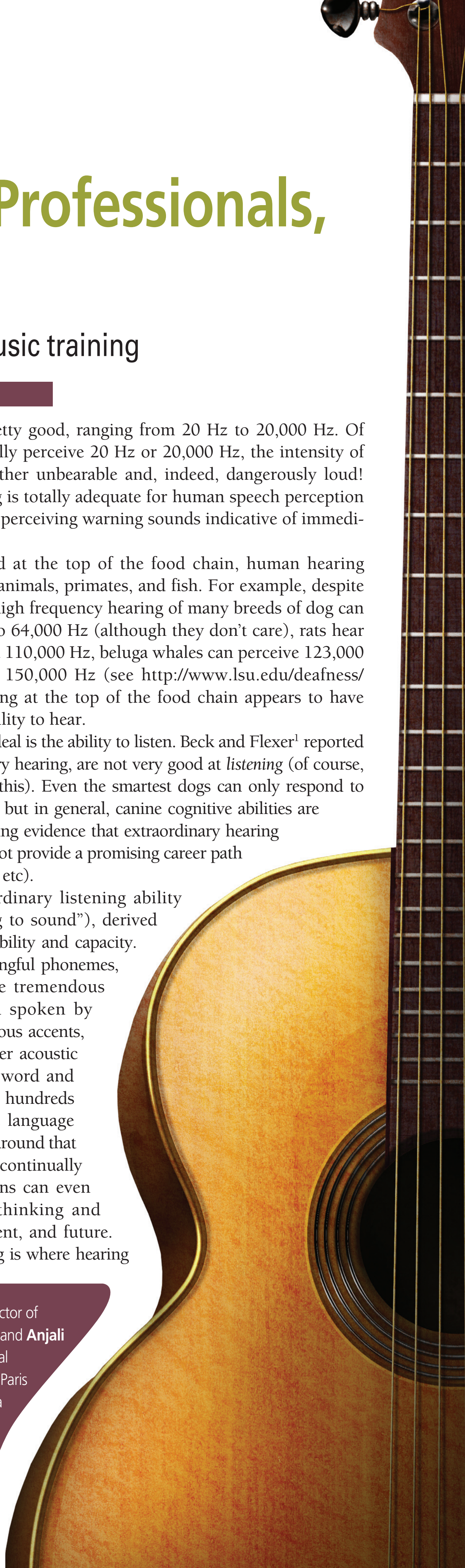
A recent *HR* article by Beck and Flexer showed how "listening is where hearing meets the brain." The present article follows this conclusion and reviews evidence for how music and music training have the ability to change our perceptual abilities—and even physically change our brains.



Normal human hearing is pretty good, ranging from 20 Hz to 20,000 Hz. Of course, for humans to actually perceive 20 Hz or 20,000 Hz, the intensity of sound would have to be rather unbearable and, indeed, dangerously loud! Nonetheless, normal human hearing is totally adequate for human speech perception (which is arguably second in line to perceiving warning sounds indicative of immediate impending danger).

However, despite being perched at the top of the food chain, human hearing pales in comparison to many other animals, primates, and fish. For example, despite similar low frequency abilities, the high frequency hearing of many breeds of dog can reach 45,000 Hz, cats can hear up to 64,000 Hz (although they don't care), rats hear up to 76,000 Hz, bats are amazing at 110,000 Hz, beluga whales can perceive 123,000 Hz, and porpoises can hear up to 150,000 Hz (see http://www.lsu.edu/deafness/HearingRange.html). So clearly, being at the top of the food chain appears to have little correlation with our limited ability to hear.

What *does* seem to matter a great deal is the ability to listen. Beck and Flexer[1] reported that dogs, despite having extraordinary hearing, are not very good at *listening* (of course, we anticipate receiving letters about this). Even the smartest dogs can only respond to perhaps a dozen words. Sorry to say, but in general, canine cognitive abilities are significantly rate-limited, thus providing evidence that extraordinary hearing in the absence of listening skill does not provide a promising career path (ie, you're still a cat, a dog, a porpoise, etc).

However, humans have extraordinary listening ability (defined here as "applying meaning to sound"), derived from our second-to-none cognitive ability and capacity. Humans organize sounds into meaningful phonemes, sentences, and paragraphs. Despite tremendous variation in the exact same word spoken by children, men, and women with various accents, spectral content, amplitude, and other acoustic variation, humans can identify the word and apply meaning to it. Humans speak hundreds of languages and, regardless of the language chosen, the human brain wraps itself around that language and organizes itself while continually applying meaning to sound. Humans can even "time travel" constantly, clearly thinking and speaking in terms of the past, present, and future. As Beck and Flexer[1] noted, "Listening is where hearing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meets brain."

Therefore, although human hearing is relatively limited, human listening is *extraordinary*. In this article, we investigate the hearing and listening ability of humans who maximize their auditory skills: musicians.

Of course, musicians hear pretty much the same as everyone else. However, their listening skills are often superior to those of non-musicians in many respects. Assuming musicians do have superior listening skills (more on that below), for some, the first question is the "chicken versus egg" or "nature versus nurture" problem.

Specifically, the first question is: Did the musician start life with a brain different from the non-musician, which caused the musician to seek musical expertise, or did the brain of the musician develop differently due to significant exposure to music? Although this question has no definitive answer at this time, Merzenich[2] noted as one "learns to listen" through motivation, practice, and intention, neurologic changes occur. Further, we believe exposure, interest, experience, knowledge, and, most likely - practice impacts the outcome.

The second question is: How much practice? Sorry to say, but 10,000 hours is just about right. That is, 4 hours daily for 2,500 days (approximately 7 years). Indeed, that's what it takes to become an expert in just about anything from chess to gymnastics, swimming, football, math, biology, dance, and more.[3,4]

Therefore, precisely because musicians spend 10,000 hours developing their skills, their brains undergo "involuntary auditory (re)habilitation." Clearly, the rationale behind 7 years of practice wasn't (directly) to change the brain; the purpose was to become a musician. However, it appears that after 10,000 hours, the brain of the musician develops finely tuned neurons and associated neuronal pathways that lead to an auditory memory or auditory memory trace, with listening skills that "carry over" to the real (ie, non-musical) world. Neurologic representations of significant acoustic sensory stimuli are referred to as *engrams*.[5]

Musicians attentively listen (apply meaning) to the musical sounds that have the most importance (to them) while non-musicians more or less hear those same sounds. Drummers listen to drums, piano players listen to piano, violinists listen to violins. That is, after extraordinary training, musicians can listen to their sound of interest within a cacophony of noise as those sounds directly impact/stimulate/

tickle engrams deep within their brains, which recognize, process, and replicate the stimuli (nearly) effortlessly, assuming one is an expert.

Behavioral Evidence

Nikjeh et al[6] stated musical training influences the central auditory nervous system (CANS), and as musical knowledge and experience increase, so too does the modulation of the CANS.

Zendel[7] compared 74 musicians (ages 19 to 91 years) to 89 non-musicians (ages 18 to 86 years) across four auditory tasks. Of note, the puretone thresholds (ie, hearing) were the same across both groups. However, musicians demonstrated "clear advantages" in listening skills. Indeed, the average 70-year-old musician understood speech-in-noise as well as the average 50-year-old non-musician. Zendel suggested a lifetime of musical expertise may help mitigate age-related listening problems. Parbery-Clark et al[8] echoed this hypothesis and suggested musical training may "reduce the impact of age-related auditory decline."

In another recent paper, Parbery-Clark et al[9] reported musicians are better at making sense of speech in challenging acoustic environments relative to non-musicians. They compared 16 musicians to 15 non-musicians with regard to the Hearing-in-Noise Test (HINT) and the Quick Speech-in-Noise Test (QuickSIN). Musicians' performance was superior on both speech-in-noise tests, and musicians demonstrated better working memory as well as superior frequency discrimination ability. George and Coch[10] took it a step further and reported musicians have enhanced working memory in both auditory and visual domains. Kraus and Chandrasekaran[11] wrote that music tones the brain for "auditory fitness."

Music training for children is likely to cause the most dramatic effects due to greater brain plasticity in younger children than older children or adults. Accordingly, researchers have performed longitudinal studies with respect to musically training a group of children over the course of several months and comparing them to age-matched controls. Moreno et al[12] showed that 6 months of musical training improved the reading ability and perception of speech

pitch across a group of 8-year-old children. Thompson et al[13] reported music training improved perception of emotion in speech in adults and children, and musical training may result in enhanced processing of speech sounds in children relative to age-matched peers with no musical training. Kolinsky et al[14] reported improved identification of lexical stress among native speakers of French (a language with *no* lexical stress) secondary to musical training. Schellenberg[15] showed a positive correlation between music lessons and IQ/academic ability in children between the ages of 6 and 11 years, even after controlling for factors such as family income and parental education.

Inherent ability and personal motivation are likely important factors, too, in the difference between musicians and non-musicians.

For example, between two groups of Finnish children with similar amounts of musical experience, those who showed better English pronunciation skills had a more pronounced electrophysiological response to changes in musical stimuli, as well as higher scores on a musicality test.[16] This implies that it may not be musical training itself, but perhaps some individual differences among the children that contributed to enhancements of auditory perception and processing.

Chandrasekaran and Kraus[17] argue that music training has been shown to improve many skills that underlie the ability to communicate despite background noise, including auditory working memory, sound source segregation, and auditory attention, and that music training would likely be a useful rehabilitative asset for children with learning disabilities. Others have also argued this; for example. Tallal and Gaab[18] propose that music training improves rapid spectro-temporal processing, which is necessary for processing speech sounds. Overy[19] showed music training caused improvements in rapid auditory processing and phonological and spelling abilities in children with dyslexia.

Why does musical training have such far-reaching and diverse benefits? Hannon and Trainor[20] argue that this may be because music training improves attentional and executive functioning skills.

Physiologic Evidence

However, musicians also show pre-attentional brain differences when compared to non-musicians. Musicians show stronger and earlier auditory brainstem responses to speech and music.[21]

> **www.hearingreview.com**
> What's so special about music? by Larry Revit, MS. February 2009 *HR.*
>
> Available at: http://www.hearingreview.com/issues/articles/2009-02_02.asp

Musicians also show enhanced and more efficient brainstem responses to a vocal emotional stimulus (an infant's cry[22]) and specialized brainstem responses to musical intervals,[23] as well as enhanced brainstem encoding of linguistic pitch.[24,25]

Musicians also show different pre-attentive brain response patterns to stimuli in regions other than the brainstem. In fact, musicians demonstrate superior pre-attentive auditory processing as shown by mismatch negativity (MMNs) recordings obtained in response to mistuned chords.[26] In a comparison of musicians' and non-musicians' N1 responses obtained while processing voiced versus unvoiced consonant-vowel syllables, non-musicians showed a difference in processing between these two while musicians did not, implying musicians have developed a different response pattern to incoming speech.[27] Musicians also show enhanced responses in the hippocampus to new and unusual music.[28]

Anatomic Evidence

Musicians often demonstrate structural differences in the brain. For example, musicians often have increased gray matter in the auditory cortices[29] as well as Broca's area,[29-31] the left primary sensorimotor cortex and right cerebellum,[32,33] visuo-spatial areas[32] and the hippocampus.[34]

Although some people may argue musicians become musicians because they have a predisposition for it (see above nature versus nurture discussion), a longitudinal study of children receiving weekly keyboard lessons over 15 months showed increases in the physical size of motor and auditory areas of the cortex, and no apparent changes in the control group.[35]

Cognitive Evidence

Strait et al[36] suggest long-term musical practice strengthens cognitive functions and may be beneficial across multiple auditory skills. Further, they suggest musical training is beneficial for "higher level mechanisms, that, when impaired, relate to language and literacy deficits."[36]

However, it's not just musicians who learn to listen attentively. In 2011, Gordon-Salant and Friedman[37] reported an extraordinary study comparing listening ability of three groups. Group One was comprised of young adults ages 18 through 30 years with normal vision, Group Two included adults 60 through 80 years who had normal (or normally corrected) vision. Like Group Two, Group Three also included adults ages 60 through 80. However, all members of Group Three had been blind for 20 years or more. Gordan-Salant and colleagues presented time-compressed speech in noise tests to the three groups. The group that performed best was Group Three—the blind adults. Indeed, the members of Group Three performed most similarly to Group One, the youngest sighted adults. The implication is the blind adults learned to listen attentively. That is, as their need for additional sensory input increased, they learned to listen more attentively to the sounds they heard.

Summary

Although the words "hearing" and "listening" are sometimes used synonymously, their true meanings are "orders of magnitude" apart. In this brief article, we have reviewed how the human brain physically, physiologically, and cognitively changes in response to sensory input, motivation, and intentional cognitive pursuits. That is, human brains are highly adaptable (ie, neuroplastic) and they change constantly based on sensory-driven, bottom-up external stimuli, as well as top-down cognitive pursuits and personal motivation. The neuroplastic potential of the human brain appears almost unlimited, given appropriate circumstances and opportunities. Thus, we believe this discussion supports the strategic, purposeful, and intentional pursuit of auditory habilitation and rehabilitation for many people with hearing loss, as the potential of auditory interventions, too, appears almost unlimited. ◗

Acknowledgement

Some concepts presented here previously appeared in *ENT & Audiology News* (November/December, 2011, Volume 20) and have been updated and revised with permission from the editor of *ENT & Audiology News.*

References

References cited here can be found in the online version of this article in the February 2012 *HR* Archives at www.hearingreview.com.

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