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 Flexer1 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 Flexer1 noted, “Listening is where hearing...
Research

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\(^8\) 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\(^9\) took it a step further and reported musicians have enhanced working memory in both auditory and visual domains. Kraus and Chandrasekaran\(^10\) 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\(^11\) showed that 6 months of musical training improved the reading ability and perception of speech
Research

pitch across a group of 8-year-old children. Thompson et al13 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 al14 reported improved identification of lexical stress among native speakers of French (a language with no lexical stress) secondary to musical training. Schellenberg15 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 Kraus17 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 Gaab18 propose that music training improves rapid spectro-temporal processing, which is necessary for processing speech sounds. Overy19 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 Trainor20 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 Musicians also show enhanced and more efficient brainstem responses to a vocal emotional stimulus (an infant’s cry22) and specialized brainstem responses to musical intervals,23 as well as enhanced brainstem encoding of linguistic pitch.24,25

Anatomic Evidence

Musicians often demonstrate structural differences in the brain. For example, musicians often have increased gray matter in the auditory cortices26 as well as Broca’s area,26-31 the left primary sensorimotor cortex and right cerebellum,32,33 visuospatial areas32 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 al36 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 Friedman37 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. Gordon-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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Music & hearing loss // Introduction

Issues and Considerations Regarding Musicians, Music, Hearing, and Listening

Why we need to learn more and do more for our patients who love music (everyone)

BY DOUGLAS L. BECK, AuD

The interaction between the human brain and sound is absolutely fascinating. I suspect you agree, as you (the reader) are very likely a Hearing Care Professional (HCP). Let’s start with some basic definitions.

**Hearing** is the perception (or awareness) of sound. However, and of significant importance, **listening** is applying meaning to sound. Humans differ from all other beings in their extraordinary ability to create language, which (more or less) applies meaning to sounds.† Human languages are essentially infinite as they describe concrete and finite things, as well as things, places, and experiences we’ve never had! Language allows us to describe particles too small to be seen with the most powerful microscopes, and infinitely large universes too large to imagine.

Our steadfast grip at the top of the food chain has little to do with hearing. Indeed, cats, dogs, whales, bats, and many other beings have hearing that encompasses different and greater spectral ranges than humans. However, what sets humans apart is their ability to apply meaning to sound (i.e., listening). Human listening ability is unmatched across all other beings, and listening is what sets humans at the top of the food chain.†

Further, and while we’re still addressing definitions, consider that to be an “expert” in anything requires some 10,000 hours of practice, training, and preparation. That is, to be an expert skier, backgammon player, musician, pilot, or swimmer requires lots and lots of practice. Ten thousand hours is the equivalent of practicing for 24-hour days for some 417 days. Or, perhaps more reasonably, most experts might practice their task 4 hours daily, every day, for 7 years. Further, by the time one has practiced music long enough to be an expert, the brain of the musician has changed!‡

**Music as Language**

Secondary to 10,000 hours of training, the musician’s brain undergoes “involuntary aural rehabilitation.” As a result, the musician’s brain no
longer responds to music in the typical way, as most non-musicians’ brains do. After 10,000 hours, the musician’s brain quite literally applies “meaning” to musical sounds. The musician cannot relegate music to background. The musician hears minor chords, major chords, key changes, 7ths, and more, and can (most often) replicate what they listen to without benefit or need of sheet music. Indeed, most musicians can listen to, interpret, and perform most contemporary (and lots of other) music via attentive listening. For the expert musician, music is absolutely a language (much like American Sign Language [ASL] is a real and meaningful language to those fluent in ASL) and the musician’s brain applies meaning to music, as the non-musician’s brain applies meaning to conventional speech (and other sounds).

Limits and Restrictions

As HCPs, we have been taught and we studied (and often only consider) a narrow view of sound. That is, we focus on the sounds that are useful for medical/diagnostic/audiologic purposes. Specifically, we (HCPs) measure threshold responses (most sounds do not occur, and are not listened to, at threshold) for pure-tones from 250 to 8000 Hz (pure-tones do not exist in the real world and human hearing ranges from 20 Hz to 20,000 Hz, and may go higher in some adolescents, up to 25,000 Hz) in a sound booth (nobody hangs out in sound booths, except KEMAR), and we measure word recognition scores and/or speech reception thresholds in quiet (that’s not the problem the patient complained of!), as well as reflexes, tympanograms, and otoacoustic emissions (OAEs). It is from these typical audiometric measures we assess, diagnose, and manage people with hearing loss.

Admittedly, the measures and protocols (noted above) evolved for rational and well-founded medical/diagnostic/audiologic reasons—but they don’t address the pragmatic listening needs and abilities of our patients.

That is, the standard test protocols do not include speech-in-noise measures (SIN) or other measures that challenge and measure “functional” hearing, and unfortunately, there are no CPT codes that facilitate the measurement and comparison of SIN scores across different technologies to help decide which technology/protocol/algorithm is best for a given patient.

Specifically, the most common complaint of the patient with the most typical sensorineural hearing loss (SNHL) is understanding speech in noise (SIN). Yet very few HCPs routinely assess SIN ability, and as such, we are left to “infer” SIN ability based on the audiogram (and other diagnostic measures). However, the correlation between the typical mild-moderate SNHL and SIN ability approaches zero. That is, the measurement of 6 to 10 pure-tone thresholds in isolation (ie, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 10,000 Hz) tells us nothing more than the type and degree of hearing loss. Threshold and typical audiometric measures are fine for the purpose of medical/diagnostic/audiologic queries such as 1) Is ear disease present? 2) Do I need to refer to a physician? 3) Is this a dangerous condition? However, the (above mentioned) typical audiometric measures fall short with respect to measuring how the two ears and the brain act and interact as a system.

Music vs Speech

The human auditory system maximally perceives (ie, hears) and understands (ie, listens and applies meaning to) sounds “pitch-matched” to the human voice. That is, the adult human ear canal maximally resonates between 2500 and 3000 Hz, and the most important sounds sounds created by the human voice (ie, the second formant or “F2”) also reside in the neighborhood of 2500 to 3000 Hz. One might say the human ear evolved to maximally perceive human speech, or perhaps the human voice has evolved to produce sounds that the human auditory system can maximally perceive. Either way, one can argue the human voice is the most important sound we hear.

If we were to compare and examine the spectral content of speech sounds in detail, we would note 71% of all speech sounds are above 1000 Hz. I'll wager all HCPs are familiar with this, and it's fair to say we each include some form of this information while counseling patients who have high frequency sensorineural hearing loss.

However, what most HCPs are less familiar with is that 72% of the fundamental frequencies of the notes on a (standard) 88-key piano fall below 1000 Hz. One might make the argument that the most meaningful acoustic information embedded within speech renders speech more-or-less a high frequency event (71% of all speech sounds are above 1000 Hz) whereas music is more-or-less a low frequency event (72% of the fundamental frequencies on the left side of the piano are below 1000 Hz).

Limits of the Audiogram: Invisible Hearing Loss

Further, as the audiogram is the gold standard hearing test, the majority of (us) HCPs don’t look deeper than the audiogram while addressing speech-in-noise and/or listening complaints. That is, children who pass pure-tone screenings are rarely afforded the benefits of additional audiologic testing, such as SIN tests or spatial tests, which document their ability to tell where sound is coming from (spatial hearing). Specifically, when a child passes a pure-tone screening (and presuming the purpose of the pure-tone screening was to declare “pass” [indicating no further testing needed] or “fail” [indicating further tests recommended]), we’re unlikely to test further. However, for many children (and adults) with normal hearing, invisible hearing loss may be present in tandem with normal audiograms.

That is, if we were to test deeper and challenge the auditory system (two ears and the brain working together as a system), we might detect auditory neuropathy spectrum disorder (ANSD) and/or auditory processing disorders (APD) and/or spatial hearing disorders (SHD)—all of which most often coexist with normal hearing! Further, by challenging and evaluating the auditory system as it’s used in day-to-day listening (to listen to speech...
in noise), we might discover significant deficiencies in the way particular brains process speech-in-noise, despite normal hearing and often beyond the expected difficulties associated with mild-moderate SNHL.

**Limits of the Audiogram: Music**

Of significant importance is the fact that 250 Hz is the lowest tone typically tested on an audiogram. “Of note” (sorry, I couldn’t help it), 250 Hz approximates “middle C” on the piano. That is, a standard audiogram absolutely and totally ignores (does not represent) hearing across the entire left side of the piano!

Audiograms are excellent diagnostic tools for ear disease, but audiograms don’t tell us enough regarding functional hearing or what the patient actually perceives within their brain with regard to music, speech in noise, or other processing-derived and processing-dependent auditory percepts. That is, the correlation between a mild-to-moderate SNHL and one’s ability to understand speech in noise approaches zero.⁴

To discern someone’s ability to understand speech in noise, it must be tested. It cannot be inferred or ascertained from an audiogram. The good news is (most often) speech-in-noise cannot be inferred or ascertained from an audiogram. It cannot be inferred or ascertained from an audiogram. “Of note” (sorry, I couldn’t help it), 250 Hz approximates “middle C” on the piano. That is, a standard audiogram absolutely and totally ignores (does not represent) hearing across the entire left side of the piano!

To discern someone’s ability to understand speech in noise, it must be tested. It cannot be inferred or ascertained from an audiogram. The good news is (most often) speech-in-noise ability is easily and efficiently determined and documented with commercially available speech-in-noise tests.⁷

Daniel Finkelstein⁸ reported that the Nobel prize-winning behavioral economist, Daniel Kahneman, describes his great intellectual breakthrough as “the realization that social science experts (including economists and HCPs) too often rely on research using samples that are too small, prompting highly unreliable conclusions.”

Consider, if we were to threshold test 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz, that would provide 10 data points that might theoretically represent thresholds (only) across the entire human hearing spectrum of approximately 19,980 Hz (20,000 minus 20). However, not only is a 0.0005% sample inadequate, but it has huge representative gaps, such as only 2 data points from 4000 to 6000 Hz (inclusive). Of course, one could argue humans only perceive some 1400 pitches between 20 and 20,000 Hz. However, even given a scant 1400 discernible pitches and using standard behavioral statistics (5% alpha level and a confidence level of 95%), we would need 302 sample points to meaningfully estimate the population (of hearing) and again, we have 10.

To be clear, I am not suggesting we test all frequencies between 20 and 20,000 Hz! However, I am suggesting we admit we often don’t test enough or gather enough data to adequately determine what it is people actually perceive via audition. Further, I believe the diagnostic battery makes perfect sense for the purpose of diagnostics, but it is not highly representative of what the patient’s brain is listening to. Of course, one cannot actually apply behavioral statistics to human hearing for multiple reasons, but I’m confident you understand the point: we measure only a very tiny portion of hearing via standard audiometric diagnostics, and we rarely measure the listening ability of the patient. Meanwhile, the most typical complaint that brings the patient into the office is their listening ability in noisy backgrounds!

**Chicken or Egg? Music or Speech?**

I’ll tackle the Chicken-Egg question first with the argument I found plausible in 4th grade. The egg came first. It was a cross-breed by-product of two other bird-like beings. Those beings mated and two eggs resulted, one contained a male, the other a female…the rest is history. Easy Peasy.

As far as whether music predated speech, or vice versa, that’s more difficult. It can be argued music is more primal and has been around longer than speech, but good luck proving it!⁹ One can also argue the quantity of angels who dance on the head of a pin, or exactly how high is high…but again, proof is the problem.

Ani Patel of The Neurosciences Institute in San Diego stated in a report by Hamilton¹ that music taps into a pre-cognitive archaic part of the brain. Patel said Charles Darwin “talked about our ancestors singing love songs to each other before we could speak articulate language…” Of note, Patel reports other species have musical ability. For example, certain monkeys recognize dissonant tones, and many birds use complicated patterns of rhythm and pitch. Some parrots move in time with the beat. Thus, it appears music may be more primal, and undoubtedly music and “musicality” exists in the absence of speech, which may indicate it appeared first…but proof?

Brandt and colleagues¹² state music underlies the ability to acquire language. They contend language is a subset of music. Further, they write “spoke language is a special type of music…” and to be clear, music came first and language arose from music. Part of this hypothesis centers on the concept that infants hear sounds and infants discriminate the sounds of language, such as the more musical aspects of speech. Of note, Brandt and colleagues describe music in terms of “creative play with sound” and report “music” implies paying attention to the acoustic features of sound without a “referential function.” The authors report typically developing children start by perceiving speech as an intentional and generally repetitive vocal performance. They say infants listen for emotional content, as well as rhythmic and phonemic content, and the meaning of the words is applied later.

**Prodigies and Music**

Just for fun, consider that child prodigies most often express their special skills in music (or math and art). Beck¹¹ notes prodigies almost always demonstrate extraordinary working memory (WM), not IQ. Boudreau and Costanza-Smith¹² report WM controls attention and information processing. Indeed, WM might be thought of as “real-time cognitive juggling” or the mind’s ability to simultaneously manage and process hearing and listening, as well as retrieving and storing information. Of course, the information most often processed by the musical prodigy is auditory, which arguably suggests there’s something special about the way some humans handle music.

**Conclusion**

The relationship between speech and music is based on multiple shared and exclusive perceptual and processing similarities and differences, respectively. We cannot assume that, because we have defined (via an audiogram) a fraction of one’s ability to perceive sound, we understand their speech-in-noise ability or disability, and we certainly cannot make presumptions about their musical ability or perception, without measuring it. Speech and music are complex and dynamic. Although speech and music acoustically interact and overlap in spectral content, they should be assessed, diagnosed, and managed as separate (perhaps complementary) acoustic phenomena as we work with patients, musicians, and colleagues.

**REFERENCES** can be found at www.hearingreview.com or by clicking in the digital edition of this article at: http://hr.alliedmedia360.com

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