Chapter 11

Toward music-based auditory rehabilitation for older adults

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> *Musical training is a more potent instrument than any other, because rhythm and harmony find their way into the inward places of the soul, on which they mightily fasten, imparting grace, and making the soul of him who is rightly educated graceful....*
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> Socrates, iv. Benjamin Jowett (trans.), The Republic of Plato (Oxford Clarendon Press, 1888): 88.

Introduction

One of the most common hearing difficulties reported by older adults is difficulty understanding speech in the presence of background noise (Pichora-Fuller et al., 2016; Pichora-Fuller & Souza, 2003; Schneider, Pichora-Fuller, & Daneman, 2010). This difficulty is often associated with requiring greater listening effort (Gosselin & Gagné, 2011) and consequently, this greater listening effort can take away cognitive resources from other cognitive domains, such as the ability to remember the content of the speech (Pichora-Fuller, Schneider, & Daneman, 1995). The more effort required for understanding speech, the more tiring this seemingly innocuous task becomes and this can have a negative impact on older adults' social life, becoming a driver of isolation and loneliness.

We also know that overall, musicians have better listening skills than nonmusicians (e.g., Parbery-Clark, Skoe, Lam, & Kraus, 2009; Zendel & Alain, 2009). This benefit persists into old age (e.g., Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Zendel & Alain, 2012, 2013, 2014), and has driven interest in using music to improve hearing abilities in older adults. Recent work has shown that short-term music training can improve hearing abilities in older adults (Zendel, West, Belleville, & Peretz, 2019; Fleming, Belleville, Peretz, West, & Zendel, 2019; Dubinsky, Nespoli, & Russo, 2019).

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The goal of this chapter is to integrate findings about musicianship and musical training in younger and older adults in order to highlight the putative mechanisms which drive the neuroplasticity that supports enhanced hearing in older adult musicians or those who have done short-term music training. Given how many older adults experience some degree of hearing loss, understanding the potential benefits of music training on hearing abilities is of critical importance. In this chapter we will focus on two mechanisms that may serve as cognitive scaffolds that could support the preservation or enhancement of hearing abilities. Introduced in Chapter 3, Age-related hearing loss (Chan & Alain, 2020), the scaffolding theory of aging and cognition (STAC) was first described by Park and Reuter-Lorenz (2009), and updated in 2014 (Reuter-Lorenz & Park, 2014). STAC consists of five major sources of influence on cognitive function in older adults: neural challenges, functional deterioration, neural resources depletion, neural resource enrichment, and cognitive scaffolding. While the first three indicate loss or decline in cognitive function, cognitive scaffolding mitigates these losses via neural resource enrichment. Neural resource enrichment refers to positive contributions to the cognitive scaffold including education, physical activity, and training, while neural resource depletion refers to negative contributions to the cognitive scaffold such as strokes, smoking, and normal aging (Reuter-Lorenz & Park, 2014).

The first cognitive scaffold we will explore is based on the idea that the motor planning system is relatively preserved in normal aging, and that auditory information, particularly speech, is often processed in parallel in parts of the motor planning system. It has been demonstrated that music training strengthens the integration of the auditory and motor systems. Music training enhances the motor responses to auditory stimuli because skilled music performance requires auditory–motor integration. This strengthened auditory–motor connection likely leads to enhanced processing of speech via the speech–motor system. The speech–motor system aids in speech understanding by making inferences about how the motor system would move speech articulators (i.e., lips and tongue) to produce the incoming speech. This strengthened auditory–motor connectivity likely drives lower level plasticity of the auditory system by continually refining both cortical and subcortical responses to incoming acoustic information. This increased refinement in responses leads to better inferences about the underlying motor gestures that produced the incoming speech and therefore aids in comprehension.

The second potential scaffold that may support the development of enhanced hearing abilities is through music perception. Emerging evidence suggests that music perception is relatively preserved in older adults, particularly the ability to process the tonal structure of music. Thus, preserved processing of musical stimuli could be used as a cognitive scaffold on which other cognitive tasks could be learned. By scaffolding speech perception onto the music perception system, it may be possible to mitigate age-related decline in the ability to understand speech in noisy environments.

For both the music perception and motor scaffolds, similar neurophysiological mechanisms likely contribute to the music training-related enhancement to understanding speech in noise. The first putative mechanism is related to enhanced neural synchrony with incoming acoustic information at the level of the brain stem. Enhanced neural synchrony would create a more robust representation of the incoming speech signal, which would facilitate the ability to understand the incoming speech. The second putative mechanism is via an improved ability to "listen" attentively to speech. Interestingly, the scant research in this field provides some evidence for both of these accounts, suggesting that music training could improve both mechanisms individually, could improve neural synchrony, which would then facilitate listening effort, or could facilitate listening effort, which could refine neural synchrony via top-down neuronal projections either online or through neuroplastic changes to subcortical structures. The rest of the chapter is divided into two sections: the case for the auditory−motor scaffold, and the case for the music perception scaffold. We then present some concluding remarks and suggestions for future research.

The case for an auditory−motor scaffold

One of the most ubiquitous daily listening tasks is understanding speech when there is background noise. This task has been referred to as the cocktail party problem and was first described by Cherry (1953). In the past decade, several studies have shown a musician advantage for various speech-in-noise tasks. For instance, one of the first studies to compare musicians and nonmusicians on a speech-in-noise task found that musicians outperformed nonmusicians on two standardized clinical assessments of the ability to understand speech in noise (i.e., QuickSIN: Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004 and HINT: Nilsson, Soli, & Sullivan, 1994; Parbery-Clark, Skoe, & Kraus, 2009). In these preliminary studies, this enhanced ability in musicians was related to both frequency discrimination (identify the higher tone) and working memory (Woodcock−Johnson III Cognitive test: Woodcock, Mather, McGrew, & Wendling, 2001) performance.

In a recent review, Coffey, Mogilever, and Zatorre (2017), examined research comparing musicians and nonmusicians on the ability to understand speech in noise and other auditory tasks that involved detecting a signal embedded in a masker. The results of this review were equivocal. Of the 29 papers included, 27 reported at least one condition where musicians outperformed nonmusicians, or musicians exhibited different neurophysiological responses using electroencephalography (EEG) or magnetoencephalography compared to nonmusicians on speech/signal-in-noise tasks. There were, however, some inconsistencies in the findings across the studies. That is, many papers reported null effects in conditions where other papers report significant effects. Coffey et al. (2017) produced a chart summarizing significant and nonsignificant musician advantages across all combinations of target signals (e.g., sentence, word, phoneme, or tone) and maskers [e.g., none, broadband noise, tone, speech-like (but not comprehensible) noise, single-talker noise, and multitalker babble noise] used among the reviewed papers. A few interesting patterns emerged from this chart. First, all studies that examined neuroelectric/magnetic responses reported differences in brain activity between musicians and nonmusicians when processing words, phonemes, and tones when no background noise was present. Second, most of the studies that found a behavioral advantage for understanding sentences, words, or phonemes in musicians did so when the masking noise was multi-talker babble. This pattern of results suggests that the musician advantage for understanding speech in noise is not just due to their improved ability to process the target speech, but also their improved ability to process the background noise when the noise is speech that can be comprehended or predicted (i.e., there is informational masking present). This enhanced processing of background speech could be due to an enhanced ability to inhibit the background speech, or to successfully divide attention and comprehend both the target speech and the background speech.

Speech in noise, rhythm, and the motor system

Emerging evidence suggests that rhythmic skills are related to the ability to understand speech in noise (Slater & Kraus, 2016). This connection is likely due to the importance of synchronizing to the rhythm/prosody of speech during speech perception. When understanding speech in background noise, an enhanced ability to entrain to the temporal envelope of speech rhythms embedded in noise would allow the listener to better guide their attention to critical acoustic features in the speech signal. Moreover, this connection could facilitate the suppression of background noise when it contains information that can be modeled by the speech–motor system (i.e., by being periodic or by containing speech with an identifiable prosody). Accordingly, the musician advantage for understanding speech-in-noise could be due to enhanced abilities in perceiving rhythm via the motor system. There is now significant evidence that the perception of rhythm involves brain structures that form the motor system (Fujioka, Zendel, & Ross, 2010; Grahn & Brett, 2007; Zatorre, Chen, & Penhune, 2007).

The motor system has long been considered an integral part of the speech perception system. Liberman and Mattingly (1985) proposed that phonetic information is perceived in a neural module that was specialized to detect the intended vocal articulations of the talker. Functional neuroimaging studies have confirmed that brain regions that were traditionally thought to be associated only with speech production are also involved in speech perception. For example, Broca's area, in the left inferior frontal gyrus, is critical for both the production and perception of speech sounds (Nishitani, Amunts,

& Hari, 2005; Watkins & Paus, 2004). Other parts of the motor system have also been shown to be involved in speech perception. For example, regions in the precentral gyrus, extending into the anterior portion of the central sulcus, are active for both the production and perception of speech sounds (Wilson, Saygin, Sereno, & Iacoboni, 2004). Further support for this claim comes from studies that have shown that lip regions of the motor cortex are activated when perceiving a [p] sound, and tongue regions of the motor cortex are activated when perceiving a [t] sound (Pulvermüller et al., 2006), as the place of articulation for producing a [p] is the lips, and for a [t] is the tongue.

Not surprisingly, the speech–motor system becomes more active in processing speech when there is background noise (Du, Buchsbaum, Grady, & Alain, 2014). Multivoxel pattern analysis using functional magnetic resonance imaging (fMRI) data revealed that specific speech tokens were discriminated better in the ventral premotor regions and in Broca's area when background noise was −6 dB SNR (speech-to-noise ratio) or above (Du et al., 2014). A similar analysis in auditory regions along the superior temporal plane was only reliable when the SNR was much higher at +8 dB SNR (i.e., quieter background noise and easier to understand; Du et al., 2014). Clearly the speech–motor system is involved in the perception of speech and it is activated to a greater extent in challenging listening situations.

When examining the benefit of musical training for speech-in-noise perception, a recent study revealed that the musician advantage for understanding speech-in-noise was related to enhanced activity in both Broca's area and in right auditory regions (Du & Zatorre, 2017). Moreover, musicians exhibited higher discriminability of speech phonemes in background noise in Broca's area and its right hemisphere homologue, the left and right premotor areas, and in auditory regions along the superior temporal plane (Du & Zatorre, 2017). Finally, functional connectivity between auditory and motor regions was found to be enhanced in musicians (Du & Zatorre, 2017). Overall this pattern of results suggests that at least part of the musician advantage for processing speech in noise comes from enhanced activation and connectivity in the speech–motor system.

One possible explanation for the connection between the speech–motor system and the musician advantage for speech processing is due to music training itself. Learning to play music requires tight coupling between the auditory and motor systems. Support for this proposal comes from longitudinal studies that compared auditory–motor training to auditory-only training in terms of cortical brain plasticity. In these studies, nonmusicians were randomly assigned to either learn to play a musical sequence on a piano (i.e., auditory–motor condition), or to listen to sequences and to detect errors in their production (i.e., auditory-only condition) over the course of 2 weeks (Lappe, Herholz, Trainor, & Pantev, 2008; Lappe, Trainor, Herholz, & Pantev, 2011). Each participant in the auditory-only condition was paired with a participant in the auditory–motor condition so that both groups were exposed to the exact same stimuli during the training. The only difference was that the auditory–motor group produced the melodies with specific finger sequences, while the auditory-only group listened to these recorded sequences and detected errors in them (Lappe et al., 2008, 2011). After the training sessions concluded, auditory abilities were assessed by using an oddball paradigm, where participants listen to sequences of tones with occasional deviants while their brain activity was monitored using EEG. The deviant tones evoke a mismatch negativity (MMN), a negative deflection automatically generated in response to a deviant, or unexpected, tone. In both studies, the auditory–motor group had greater training-related enhancements in their ability to detect errors, and greater enhancements to the MMN (Lappe et al., 2008, 2011). This suggests that one of the critical components of music training is the motor component and supports the idea that plasticity in the auditory–motor pathway can lead to enhanced speech perception in musicians. Evidence for such plasticity is discussed next.

Auditory–motor plasticity

At the neurophysiological level, using the frequency following response, it has been shown that the subcortical encoding of speech presented in background noise is more robust in musicians compared to nonmusicians (Musacchia, Sams, Skoe, & Kraus, 2007; Parbery-Clark et al., 2009; Russo, Nicol, Zecker, Hayes, & Kraus, 2005; Wong, Skoe, Russo, Dees, & Kraus, 2007; see Chandrasekaran & Kraus, 2010; Kraus & Chandrasekaran, 2010 for reviews). Although these enhancements are at the subcortical level, it is thought that they are due to top-down control or changes in long-term potentiation, which arise via the corticofugal pathway (Sörqvist, Stenfelt, & Rönnberg, 2012; Suga, 2008; Suga & Ma, 2003; Tzounopoulos & Kraus, 2009). This idea was based on the reverse hierarchy theory, which states that perceptual learning is a top-down process, and as perceptual learning progresses, the associated neural plasticity will move to lower level brain structures (Ahissar & Hochstein, 2004). Short-term music training (2 weeks) that involved both an auditory and motor component was found to improve auditory processing abilities and enhance cortical responses to auditory oddballs (Lappe et al., 2008, 2011). It is therefore possible that music training first impacts the connection between the auditory–motor system at the cortical level, and then as music training continues, neuronal connections in subcortical structures are refined via top-down mechanisms.

Accordingly, enhancements to speech perception due to music training could start at the level of the motor system in the cortex. For the information from the motor system to descend the corticofugal pathway and impact auditory neurons, there would have to be a consistent mapping of specific motor activations to specific acoustic information. Indeed, the shape of the vocal tract, especially the shape and orientation of the tongue is directly correlated with the frequency of the first three formants (F1, F2, F3) in vowel sounds (Ladefoged, Harshman, Goldstein, & Rice, 1978). For instance, higher tongue positions are associated with a lower frequency F1, while lower tongue positions are associated with a higher frequency F1. Similarly, forward tongue positions are associated with a higher frequency F2, while back tongue positions are associated with a lower frequency F2. Thus production of any vowel sound is associated with a specific tongue position. Interestingly, when speech is presented in background noise, the place of articulation that leads to variability in F2 is the most difficult feature to detect based on acoustic features alone; however, it is one of the easier features to detect based on the movement of a talker's lips (Miller & Nicely, 1955). Interestingly, musicians have greater neural differentiation of the F2 consonant to vowel transition compared to nonmusicians (Parbery-Clark, Tierney, Strait, & Kraus, 2012). Older musicians exhibited a similar advantage compared to older nonmusicians (Parbery-Clark, Anderson, Hittner, & Kraus, 2012). Importantly, the differences between musicians and nonmusicians were further enhanced when speech material was presented with corresponding videos of lip movements (Musacchia et al., 2007). This pattern of results suggests that the observation of motor movements can further facilitate speech processing in musicians. Over time, this strengthened auditory–motor connection could give rise to neuroplastic modulations that extend to the level of the brain stem via the corticofugal pathway. This plasticity, while based on a visual input, would not require a visual input for support, as it would be related to an enhanced encoding of acoustic features that relate to a specific pattern of articulation. If observing motor movements is a critical part of this plasticity, then it is possible that musician advantages for auditory processing are driven by stronger integration between the auditory and motor systems.

The motor system as a scaffold

In younger adults, the association of musicianship to enhanced processing of speech appears to be related to enhanced activity in the speech–motor system (Du & Zatorre, 2017). In older adults, preliminary evidence suggests that short-term music training improves the ability to process speech due to functional enhancements in brain regions involved in the speech–motor system (Fleming et al., 2019; Zendel et al., 2019). At the same time, research examining age-related changes in speech production revealed no significant age effects in motor or premotor regions (Sörös, Bose, Sokoloff, Graham, & Stuss, 2011; Tremblay, Dick, & Small, 2013). If the motor system that supports speech production is relatively preserved in older adults, then the motor system may be a candidate to develop cognitive scaffolds from which other abilities can be refined, such as speech perception.

This motor system scaffold could develop automatically due to the intrinsic connections between the auditory, sensory, and motor systems. The representation of incoming auditory information is enhanced in belt areas around the primary auditory cortex, when it is paired with tactile sensory information (Foxe et al., 2002; Kayser, Petkov, Augath, & Logothetis, 2005). This pairing would occur naturally when playing piano, and would provide a more robust representation of the auditory information as it is processed. This enhancement is critical, as developing a motor skill (e.g., playing a musical instrument) requires gathering and processing of sensory information related to the action (Wolpert, Diedrichsen, & Flanagan, 2011). Thus when learning to play a musical instrument, the learner must integrate the auditory information in order to refine the associated motor action in the future. Over time, this leads to a greater connectivity between the auditory and motor systems and may lead to plasticity in motor and premotor cortices and regions that connect the auditory and motor systems. Given that age-related changes in the peripheral auditory system decrease the quality of the incoming acoustic signal, this strengthened pathway might be exploited to help refine this impoverished incoming auditory information. Indeed, integration of multiple modalities can improve the processing of a single sensory modality (Ernst & Bülthoff, 2004). In music training, the constant pairing of an auditory input with both a motor command and sensory feedback via the finger (e.g., in the case of playing piano) would increase the cortical representation of the auditory signal. After training, the strengthened auditory–motor system may better process speech information. Given that the motor system is naturally involved in speech perception the enhancement would occur automatically. The result would be that speech processing is enhanced by music training.

Applying the speech–motor system scaffold

There is already some evidence that instrumental training leads to improved speech-in-noise perception in older adults due to neuroplasticity in auditory–motor regions. Zendel et al. (2019) and Fleming et al. (2019) randomly assigned older adults to receive piano lessons, video game training, or no activity for a period of 6 months and evaluated speech-in-noise performance (word detection in silence, and quiet and loud multi-talker babble background noise) as well as late positive event-related potential (ERP) components extracted from EEG data before, half-way, and after training (or no training in the case of the no-contact controls). Performance when background noise was loudest improved only in the group that received music training (Zendel et al., 2019). That is, 6 months of music lessons improved the ability to understand speech in noise in older adults. In terms of cortical effects, participants in the music group showed an increased positivity over fronto-left electrodes that were related to their increased ability to understand speech in noise (Zendel et al., 2019). A source analysis of the ERP data

(Zendel et al., 2019) and fMRI data collected in parallel (Fleming et al., 2019) suggest that these enhancements were related to structures in the speech–motor system, including the left inferior frontal gyrus (Broca's area), bilateral middle frontal gyrus (including the supplementary motor area), the supramarginal gyrus, and the cerebellum (Fleming et al., 2019; Zendel et al., 2019). Training-related change in these regions was associated with enhanced ability to understand speech across all levels of background noise, supporting the connection between speech understanding and the speech–motor system (Fleming et al., 2019). Moreover, other research has identified these regions as being critical for both speech production and speech perception tasks, further supporting the idea that they are part of the speech–motor system (Vigneau et al., 2006).

These results are encouraging, demonstrating an improvement in speech-in-noise perception and neural processing in older listeners due to a late-life musical training program. Such training programs could be developed for various instruments such as piano, guitar, ukulele, bass, percussion, or singing. These instruments are suggested as they are relatively accessible in terms of fine motor movement and cost (as opposed to the violin for example) and are likely to attract interest. Training programs should continue to be implemented and evaluated, focusing on using cognitive scaffolding through motor tasks which can be paired with auditory processing, memory, attention, or executive functions. These cognitive abilities have all been associated with understanding speech in noise, and enhancing them could also improve the ability to understand speech.

The case for a music perception scaffold

There is a long history of examining auditory processing abilities in musicians. Many early studies demonstrated that musicians performed better than nonmusicians on music-based auditory perceptual tasks. One of the earliest studies found that musicians were better than nonmusicians at recognizing melodies presented earlier in the experiment when melodies were presented monaurally to the right ear (Bever & Chiarello, 1974). Given that the left hemisphere was thought to be the center of language processing, a right ear advantage[1] suggested that musicians treat music like a language (Bever & Chiarello, 1974). This finding provided the foundation for many studies on the impact of music training on hearing abilities such as pitch, rhythm, harmony, and timbre perception, as well as auditory streaming and attentional allocation.

Over the next decades, numerous studies demonstrated that musicians had better auditory processing abilities in both musical and nonmusical

1. Due to brain lateralization, sensory input is processed in the opposite hemisphere of the brain: all input from the right side of the body is processed in the left hemisphere and vice versa.

situations. For example, musicians, compared to nonmusicians, perceived differences in pitch more categorically, like notes in a musical scale (e.g., like a language where pitch is a unit; Zatorre & Halpern, 1979); musicians could identify tone intervals better than nonmusicians (Siegel & Siegel, 1977); musicians could identify the emotional content of a speech prosody better than nonmusicians (Nilsonne & Sundberg, 1985); musicians could identify chord changes better than nonmusicians (Morais, Peretz, Gudanski, & Guiard, 1982); and musicians were better than nonmusicians at identifying tempo changes in musical sequences (Madsen, 1979). Subsequent research revealed that even some very basic auditory processing abilities were enhanced in musicians compared to nonmusicians. For example, auditory streams persist longer in musicians (Beauvois & Meddis, 1997); musicians are less susceptible to timbral influences on pitch perception (Pitt, 1994); musicians have enhanced frequency discrimination abilities (Besson, Schön, Moreno, Santos, & Magne, 2007; Micheyl, Delhommeau, Perrot, & Oxenham, 2006); and musicians have enhanced sound duration discrimination abilities (Jeon & Fricke, 1997), when compared to nonmusicians. This list is not exhaustive and only highlights the earliest investigations into the auditory advantages observed in musicians.

There is now a small, but significant body of literature highlighting the benefits of musical training on hearing abilities for nonmusical material in older adults (Alain, Zendel, Hutka, & Bidelman, 2014; Kraus & Chandrasekaran, 2010). Two of the first studies that examined hearing abilities in older adult musicians found advantages for lifelong musicians (Parbery-Clark et al., 2011; Zendel & Alain, 2012). Parbery-Clark et al. (2011) compared older (i.e., 45–65 years) musicians and nonmusicians on three speech-in-noise tasks: QuickSIN (Killion et al., 2004), HINT (Nilsson et al., 1994), and WIN (Wilson, 1993). They found a musician advantage across all three tasks that was related to both auditory working memory (subtest of the Woodcock–Johnson III Test of Cognitive Abilities; Woodcock et al., 2001) and auditory temporal acuity (backwards masking subtest of the IHR Multicenter Battery for Auditory Processing; Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010). Zendel and Alain (2012) compared musicians and nonmusicians who ranged in age from 18–91 years, on the QuickSIN test and found slower rates of age-related decline on the QuickSIN in musicians compared to nonmusicians. In this study, the average 70-year-old musician performed as well as the average 50-year-old nonmusician on the QuickSIN test. Zendel and Alain (2012) also reported that older musicians were better than older nonmusicians at segregating concurrent sounds based on harmonic structure, and detecting a small silent gap.

Neurophysiological evidence

At the level of the cortex, auditory processing can be assessed by scalp-recorded brain potentials (i.e., ERPs). One interesting pattern that has come out of this work is that aging impacts how acoustic information is processed. In general, older adults are able to rely on attention-dependent processing (i.e., using knowledge to make predictions, focusing on acoustic features relevant to the task, etc.) to overcome age-related decline in the transduction and encoding of acoustic information. In other words, while hearing abilities decline in older adults, their listening skills improve to compensate (Pichora-Fuller et al., 2016). This "listening" benefit is likely further enhanced in musicians or by musical training, which explains why older musicians can understand speech in noise better than older nonmusicians (Alain et al., 2014).

One way to observe how music is processed is to use ERPs. ERPs represent phase-locked neural responses to an auditory stimulus. ERP responses from around 50 ms poststimulus onset until about 250 ms are thought to represent activity from the primary auditory cortex, and secondary auditory regions along the superior temporal plane (Näätänen & Picton, 1987). The peaks of these responses are referred to by their electrical polarity ([P]ositive or [N]egative), and the order in which the peak occurs. Typically, a transient acoustic stimulus will evoke a P1–N1–P2 response, regardless of the attentional state of the listener. A P3 response is usually evoked when a listener is asked to attend to the stimulus and make some sort of a judgment (Polich, 2007). In older adults, there have only been a few studies that have investigated how musicianship moderates the auditory evoked response. Aging tends to increase the amplitude of the P1–N1–P2 component of the auditory evoked response, and this enhancement is thought to be related to a decrease in frontal inhibitory activity (Alho, Woods, Algazi, Knight, & Naatanen, 1994; Knight, Hillyard, Woods, & Neville, 1980; Zendel & Alain, 2014). This creates a challenge when interpreting the results of auditory ERP studies comparing older and younger musicians and nonmusicians because many studies comparing younger musicians to nonmusicians report enhanced auditory evoked responses that are associated with enhanced hearing due to neuroplasticity (Koelsch, Schröger, & Tervaniemi, 1999; Shahin, Bosnyak, Trainor, & Roberts, 2003; Shahin, Roberts, Pantev, Trainor, & Ross, 2005). In other words, when comparing older adults to younger adults, the larger P1–N1–P2 in older adults is usually associated with a decline in hearing abilities due to decreased frontal inhibition, whereas when comparing younger musicians to nonmusicians, the enhanced P1–N1–P2 in musicians is associated with improved hearing abilities due to neuroplasticity associated with music training. These neuroelectric brain responses are usually evoked by short transient tones, and thus are thought to represent the synchronized neural activity evoked by a transient tone.

A study examining concurrent sound segregation, or the ability to separate simultaneously occurring sounds, found that the older musician advantage was related to attention-dependent processing (Zendel & Alain, 2013). In this study, participants were presented with a harmonic complex, where the third harmonic could either be in-tune with the complex, or mistuned by 1%, 2%, 4%, 8%, or 16%. EEG data was collected while participants indicated whether they perceived one or two distinct sounds, where greater mistuning resulted in an increased likelihood of perceiving a complex tone and a pure tone simultaneously rather than a single complex tone (Moore, Glasberg, & Peters, 1986). Older and younger musicians were more likely to report hearing a second tone when the harmonic complex was mistuned by above 2% (Zendel & Alain, 2013). Despite the similarities between older and younger musicians in terms of their perceptual judgments, the electrophysiological data revealed a different pattern of results. During passive listening, a mistuned harmonic complex evoked an object-related negativity (ORN) that overlapped the N1 (Alain, Arnott, & Picton, 2001). During active listening, where participants made a perceptual judgment, the ORN was followed by a positive deflection that occurred around 400 ms (P400) (Alain, Arnott, et al., 2001). This pattern suggests that the ORN represents the automatic detection of acoustic features that suggest two simultaneous sound sources, while the P400 represents the perception of two simultaneous sound sources. In younger adults, both the ORN and P400 were enhanced in musicians compared to nonmusicians (Zendel & Alain, 2009, 2013). In older adults, the ORN was similar between musicians and nonmusicians, but the P400 was enhanced in older musicians compared to the other three groups (Zendel & Alain, 2013). Given that the P400 is thought to index the conscious perception of two separate sound objects, the results suggest that older musicians overcome age-related decline in the early stages of auditory processing through enhanced listening.

In another study that examined the cortical response to a harmonic complex, an age-related increase in P1 amplitude was observed, but musicians, both older and younger, had a reduced P1 amplitude compared to age-matched nonmusicians (Zendel & Alain, 2014). Interestingly, this difference was observed only during a passive listening task, and was eliminated when participants were asked to make a judgment about the incoming acoustic stimulus (i.e., active listening task). During active listening, late positive activity from right auditory regions, along the superior temporal plane, was enhanced in older musicians compared to older nonmusicians, younger musicians, and younger nonmusicians (Zendel & Alain, 2014). Activity in the right auditory cortex is associated with processing spectral information from the incoming acoustic stimulus (Warrier et al., 2009; Zatorre, 1988), suggesting that older musicians are better able to focus their listening to acoustic features that are critical for the task being performed. The underlying cause of this enhanced listening could be due to either long-term neuroplasticity in conscious auditory perception, or to enhanced motivation of older musicians to perform well on hearing tests.

The preservation of music perception

In addition to enhanced "listening" abilities in older adults, which appears to be further enhanced in older musicians, music perception also seems to be relatively preserved in older adults. To date, there have only been a few studies that examined how music perception is affected by age. Investigations of tonal structure using a classic probe tone paradigm (Krumhansl & Kessler, 1982) in older listeners indicated that the perceived stability of tonic chord tones compared to scale tones and chromatic tones is sharpened in older adults (Halpern, Kwak, Bartlett, & Dowling, 1996). A study by Lynch and Steffens (1994) compared mistuning detection abilities in tonal and atonal music in younger and older listeners and found that older listeners' performance was only worse than younger listeners' performance in atonal music, but similar for tonal music. Neurophysiological investigations of tonal processing have revealed that electrical brain responses and the ability to classify or detect unexpected, or out-of-tune notes in a melody are similar in both older and younger adults (Halpern et al., 2017; Lagrois, Peretz, & Zendel, 2018).

The study of musical memory generally finds adverse effects of age on memory performance for music (Andrews, Dowling, Bartlett, & Halpern, 1998; Bartlett, Halpern, & Dowling, 1995; Dowling, Bartlett, Halpern, & Andrews, 2008; Halpern & Bartlett, 2002; Halpern, Bartlett, & Dowling, 1995, 1998), where older adults achieve fewer hits and more false alarms on same/different and recognition tasks where contour, tempo, and source identification are manipulated. However, one study investigated similarity judgements between melodies that were manipulated in terms of mode, rhythm, and contour found that older and younger listeners perceived similarity in the same way, where melodies that differed in mode were perceived as more similar than melodies that differed in contour, which in turn were perceived as more similar than melodies that differed in rhythm (Halpern et al., 1998). The only exception to this pattern were older musicians, who found melodies differing in rhythm more similar than melodies differing in contour (Halpern et al., 1998). Older listeners were also no different from younger listeners at identifying very slow melodies, though they could not recognize these melodies when played at a tempo as fast as could be recognized by younger listeners (Andrews et al., 1998; Dowling et al., 2008). This body of literature suggests that given enough time to "digest" the musical material being presented, older adults can perform memory and recognition tasks just as well as younger listeners when using musical stimuli. Importantly, most real-world music is within these parameters. Furthermore, while episodic memory suffers with age, older adults appear to have preserved semantic memory for music, even in older adults with mild-to-severe dementia (Cuddy et al., 2012; Vanstone et al., 2012). Although there is a general cognitive slowing with age, pairing preserved cognitive abilities with music perception tasks that are most similar to real music may be the key to training programs designed to improve day-to-day hearing abilities in older adults.

Applying the music perception scaffold

Having discussed how lifelong musical training can slow the decline of auditory–cognitive abilities and how music perception seems to be generally preserved in old age, we can offer some suggestions for how a music-based training program could improve listening abilities in older adults. Since basic music perception skills such as pitch, time, mode, contour, and harmony perception seem preserved in older adults, we can use this existing scaffold to train and improve higher-level listening skills. After all, evidence suggests that while older musicians' hearing declines equally to nonmusicians', musical experience trains them to be better *listeners* (Alain et al., 2014). The goal is that focusing on refining these skills in a training program will have a similar effect to formal musical training. The listening skills we will discuss are auditory stream segregation and musical memory.

Assuming a training program spanning several weeks, training could be divided into multiple types of tasks to provide variation with varying levels of difficulty within each task. In the case of auditory stream segregation, one type of task could be to detect a deviant (e.g., timbre or pitch) in a familiar melody interleaved with distractor tones (Dowling, 1973). Within this task, difficulty can be adaptively adjusted to each individual by modifying the similarity between the distractor tones and the familiar melody, where more similarity equates to more difficulty. Familiar melodies could be tailored to each individual for a more engaging experience that is also easier as there is no need to learn new material. There is also evidence that older adults perceive speech in music better when music is familiar than when it is unfamiliar (Russo & Pichora-Fuller, 2008). A variation of this task could be to perform the same deviant detection with unfamiliar melodies written for the training program. This would not only engage streaming skills but also memory for new content.

A task with more ecological stimuli might be to focus on a particular instrument or voice in a piece of music. For example, in a string quartet it would almost always be easier to focus on the violins but more difficult to pick out the cello line (picking out the viola line could be left for extra keen individuals!). Orchestral works provide a much wider range of instruments to choose from. Again, working with familiar and loved works, the individual could either follow program suggestions of easy/medium or difficult instruments to focus on, or choose their own desired level of challenge. While this task does not provide any objective measurement of performance, it is designed to be enjoyable, engaging, and challenging while focusing on developing auditory stream segregation skills. As older adults succeed at this task, speech could be used in place of instruments as targets and background in order to scaffold speech perception onto music perception abilities.

Turning to musical memory, a straightforward task could be to either have the individual sing or playback a given novel melody, where that melody is adaptively modified in terms of complexity. Complexity can be manipulated in terms of length of the melody (longer = complex), number of contour changes (more = complex), degree of tonality (low = complex), and interval patterns (leaps = complex). This type of task would require transcription software capable of measuring the degree of success of the singing or playback. If this is not possible, a same/different or deviant detection task can also be applied here.

The tasks described above are only a few suggestions for the application of the music perception scaffold to improve listening skills in older adults. Given that music perception is preserved and music listening is still widely enjoyed in older adults, narrowly training specific listening skills that musicians develop throughout their own training should impart similar benefits. The auditory streaming tasks mirror musicians' transcription and ensemble listening skills while the musical memory tasks mirror both transcription and performance memorization skills. We hope that these suggestions provide some exciting research avenues, or at the very least, productive discussions in the field.

Summary and conclusion

It is likely that hearing abilities in older adults can be improved using music as a cognitive scaffold. The two potential cognitive scaffolds are the speech–motor system and music perception, both of which demonstrate preservation in older age. Since they are preserved, these mechanisms could potentially act as cognitive scaffolds through which older adults can develop better listening skills that can in turn improve their speech-in-noise perception. New forms of auditory rehabilitation could be examined based on this cognitive scaffold model. While the speech–motor-based training strengthens connectivity in the speech–motor system through music performance, the music perception-based training targets high-level listening skills through music listening. These types training programs could be combined, with some performance and some listening, or implemented alone. The choice of training program could also depend on the individual seeking training. For example, motor abilities could be an important factor to consider when choosing a training program. Restricted motor abilities may exclude instrumental performance but could be integrated into the listening-based training program by developing tasks that include tapping or conducting for example. Other individual factors may also play a role, for example, cognitive abilities, education level, or hearing abilities could impact success in the proposed training programs. Another important factor to consider is the length of these training programs. Current studies range from 2 weeks of training (Lappe et al., 2008) to 6 months of training (Zendel et al., 2019) with positive results. However, whether these positive effects are maintained in the long term is unknown and future research will need to explore length and intensity (i.e., hours per week) of training for best results. As research answers these questions, individualized forms of music-based auditory rehabilitation could become important at preserving quality of life for older adults.

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