Chapter 12
Aging, Hearing Loss, and Speech Recognition: Stop Shouting, I Can't Understand You

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12.1 Introduction

My interest in age-related hearing loss began in 1984, as my father (age 75) exhibited significant noise-induced hearing loss but refused to wear a hearing aid. How frustrating for an audiologist to be unable to convince a parent to use amplification that would benefit him significantly. Eventually, his additional age-related hearing loss progressed to the degree that he used his hearing aid routinely, but he continued to experience difficulty in understanding speech in all but quiet face-to-face situations. In later years, my mother complained of specific challenges listening to accented English on televised broadcasts. These and other complaints of my elders inspired me to investigate the nature of age-related hearing loss and specifically, the factors underlying older listeners' speech recognition problems.

Is hearing loss an inevitable consequence of the aging process? Are humans destined to say, "I can hear you but I can't understand what you are saying"? Communication with others is fundamental to human existence and is the essence of social interaction; untreated decline in auditory abilities with age often results in social isolation and the appearance of dementia. A great deal is now known about the range of anatomical and physiological changes in the auditory system that occurs with age, but the functional consequences for communication and the benefit of assistive technology and rehabilitation are currently an intense area of scientific inquiry. How well an individual older listener understands speech in degraded situations, including poor acoustic environments and the speech of less-than-ideal talkers, depends not only on auditory capacity but also on cognitive and multisensory integration abilities. Also of great interest are lifestyles that young and middle-aged adults can embrace to promote healthy auditory aging to prevent progressive hearing loss with advancing age and preserve the ability to process distorted speech signals or speech in noisy environments. This chapter briefly reviews that state of knowledge on age-related hearing loss from 20 years ago (ca. 1992) and highlights some significant findings in recent years that have crystallized the current view of mechanisms underlying presbycusis (defined as hearing loss associated with the aging process) and its functional consequences. The chapter culminates in suggestions for emerging areas of research aimed at unraveling the persistent and interrelated issues of understanding and improving older listeners' difficulty perceiving speech in everyday communication situations.

12.2 Historical Perspective

12.2.1 Epidemiology

In 1992, the overall prevalence rate of hearing loss among those 65 years and older was generally accepted as approximately 30% in the United States. It was well known that older men exhibited poorer hearing sensitivity than older women, especially in the higher frequencies, and the typical audiogram was mild-to-moderate in degree with a gradually sloping configuration. Data from the hearing aid industry suggested that the acquisition rate of hearing aids among the older hearing-impaired population was approximately 23%, and surveys suggested that about half of these hearing aids remained in the drawer. At that time, ear-level analog devices were common, although hybrid analog-digital technology was beginning to emerge. The quality of amplified sound, especially in noise, and the stigma associated with hearing loss were often cited as the most common reasons for rejecting hearing aids.

12.2.2 Models of Presbycusis

The classic work of Harold Schuknecht (1974) identified four forms of presbycusis that were based on human temporal bone studies and corresponding audiometric profiles: (1) sensory, associated with loss of cochlear hair cells particularly in the basal turn; (2) metabolic, attributed to atrophy of the stria vascularis; (3) cochlear conductive, theorized as a stiffening of the basilar membrane; and (4) neural, ascribed to deterioriation of neurons comprising the auditory branch of cranial nerve (CN) VIII. Each form of presbycusis was associated with specific auditory manifestations, although Schuknecht and Gacek (1993) recognized that multiple forms of presbycusis can coexist with an additive effect on auditory thresholds. Others suggested the existence of "conductive" presbycusis, thought to be associated with elastic changes to the tympanic membrane, fixation of the ossicles, arthritic changes to muscles and ligaments, and Eustachian tube dysfunction (Glorig & Davis, 1961). Despite these possible anatomical changes, a small proportion of older people exhibit conductive hearing loss (Cruickshanks et al., 1998). There was also evidence of deterioration of the central auditory pathways in humans (Kirikae et al., 1964). Willott (1991) theorized that damage to the central auditory pathways could result either from direct deterioration of central structures (called the central effects of biological aging [CEBA]) or from the subsequent, retrograde effects of peripheral pathology on central nervous system (CNS) structures (called the central effect of peripheral pathology [CEPP]). Anatomical studies of aging human brains indicate a decrease in the volume of nuclei in the central auditory nervous system, a decrease in the number of dendrites and dendritic spines in the central auditory pathways, and considerable variability in the surviving neuronal population (Willott, 1991) lending some support to the theory of central biological aging. Nevertheless, strong evidence from animal studies (C57 mouse) also supports secondary effects of peripheral pathology, especially as a result of high-frequency sensorineural hearing loss (Willott, 1991).

12.2.3 Speech Understanding Performance

Prior to 1992, the effects of auditory aging were quantified by a performance comparison between younger listeners with normal hearing and older listeners with hearing loss on speech recognition measures conducted in quiet, noise, and reverberant environments. Differences between groups were typically ascribed to aging, but differences in signal audibility could also have accounted for group effects. One noteworthy exception was a study by Dubno et al. (1984), which showed that older listeners performed more poorly than younger listeners with matched audiograms, and hearing-impaired listeners performed more poorly than normal-hearing listeners on a low-context sentence recognition test presented in a multitalker babble background. The authors interpreted this finding as reflecting an audibility factor that limits performance for hearing-impaired listeners and a distortion factor that limits performance for older listeners; these two factors may combine in certain signal and noise conditions to produce excessively poor performance among older hearing-impaired listeners. A notable finding in this study is that the availability of contextual cues had a dramatic effect on the performance of older listeners, reducing the age differences considerably.

Early investigations also examined the effects of aging on recognition of time-compressed speech, a simulation of natural, rapid speech (e.g., Wingfield et al., 1985). These investigations attempted not only to quantify anecdotal reports of older listeners' difficulty understanding rapid speech, but also to investigate a prominent theory of cognitive aging that there is a decline in speed of sensory and perceptual encoding with increasing age (Salthouse, 1996). Related studies examined perception of reverberant speech by younger and older listeners (e.g., Helfer & Wilber, 1990). Findings from these investigations generally showed that older listeners performed much more poorly than younger listeners, but again, differences in auditory sensitivity between younger and older groups could have contributed significantly to observed group effects. All of these early studies revealed large variability in the performance of older listeners; few of them examined differences in cognitive abilities that may have contributed to individual differences. Finally, investigations in this era were confined to assessing unimodal, auditory-only speech recognition performance.

12.3 Key Findings in Recent Years

12.3.1 Epidemiology

Hearing loss among the older population in the United States is more widespread than reported previously, with an overall prevalence rate converging at 46% among those 48 years and older (Cruickshanks et al., 1998). Using a pure-tone average in the speech frequencies (500, 1000, 2000, and 4000 Hz) exceeding 25 dB hearing level (HL) in the better ear to identify hearing loss, Agrawal et al. (2008) reported a prevalence rate of 49% among 60- to 69-year-olds and Lin et al. (2011) reported a prevalence rate of 63.1% among those 70 years of age and older. Applying these hearing loss prevalence rates to the population older than 65 years (U.S. Census Bureau, 2011) indicates that there are approximately 20 million senior citizens with significant hearing loss in the United States today, and by 2035, there will be approximately 38 million. These data underscore the imperative to find realistic solutions to the communication problems related to aging and hearing loss. Also reported in recent epidemiologic studies is the frequency of hearing aid use among the older population, stratified by degree of hearing loss. In the population older than 70 years, hearing aids were used by 40% of those with a moderate hearing loss but only by 3.4% of those with mild hearing loss (Lin et al., 2011). Individuals with a moderate or greater degree of hearing loss report significant hearing handicap (Weinstein & Ventry, 1983); thus, a take-up rate of only 40% by older people with moderate hearing losses continues to reflect poor acceptance of hearing aids.

12.3.2 Models of Presbycusis

Animal models of age-related hearing loss have revealed three consistent age-related changes in the auditory periphery, and these vary by the specific animal model. In the Mongolian gerbil (*Meriones unguiculatus*), a mammal that exhibits hearing sensitivity similar to that of humans, the principal change in cochlear anatomy is atrophy of the stria vascularis, which in turn reduces the endocochlear potential (Schmiedt, 2010). The resulting hearing loss is mild in degree in the low frequencies, sloping to a moderate-to-severe hearing loss in the high frequencies, which is remarkably similar to the audiometric configuration reported for older humans with prebycusis (Schmiedt, 2010). Deterioration of stria vascularis is also a prominent change in Fischer 344 rats (Syka, 2010). In the C57 mouse model of age-related hearing loss, however, the primary locus of change in the auditory periphery is loss of outer hair cells in the basal turn of the cochlea (Sprongr et al., 1997). All animal models consistently show widespread shrinkage and loss of spiral ganglion cells of cranial nerve (CN) VIII with increasing age (Schmiedt, 2010). Unlike humans, animals in these studies are raised in a quiet environment with a well-controlled diet, suggesting that these observed age-related changes are not associated with acquired insult to the auditory periphery. The work of Kujawa and Liberman (2006) suggests that in humans, exposure to intense noise at a young age initiates not only a rapid deterioration of outer hair cells but also a slow process of progressive deterioration of CN VIII trunks, which may manifest as accumulated damage to spiral ganglion cells among older adults.

There is evidence of neural deterioration with age at every nucleus and the connecting pathways throughout the central auditory nervous system (Willott, 1991). A reduction in neurochemical inhibitors with age has also been observed at many of the nuclei of the central auditory nervous system, including the dorsal cochlear nucleus, inferior colliculus, and auditory cortex (e.g., Caspary et al., 1990). Finally, altered physiologic responses with age in processing brief temporal gaps have been recorded in CBA mice in the inferior colliculus (Walton et al., 1998). Taken together, these findings from animal models confirm that auditory aging occurs independently of lifestyle (noise exposure, diet, ototoxicity), deterioration of the stria vascularis and CN VIII are prominent peripheral changes, a reduction in neural inhibition is widespread throughout the central auditory nervous system, and deficits in auditory temporal processing at central levels accompany the aging process.

12.3.3 Factors Contributing to Speech Understanding Problems

In the intervening 20 years, a number of studies have examined the sources of individual variability in speech recognition performance among large cohorts of older listeners. These investigations typically applied a multifactorial approach to identify a set of measures (auditory sensitivity, auditory processing, cognitive) that predicts speech recognition performance in quiet, noise, and other forms of degradation. Invariably, these studies identified hearing sensitivity as the most important factor that contributes to speech understanding performance in quiet and noise (e.g., Humes et al., 1994), and this finding has been replicated in cross-sectional designs as well. Nevertheless, the variance in performance accounted for by hearing sensitivity approximated 40% to 60% across studies, indicating that there are additional factors that contribute to older listeners' diminished speech recognition performance.

Auditory temporal processing refers to the ability to detect or discriminate brief acoustic signals or those presented at a rapid rate. Older listeners consistently show poorer auditory temporal processing than younger listeners with comparable hearing sensitivity for tonal signals and/or noise bursts on measures of gap detection (Schneider et al., 1994), duration discrimination (Fitzgibbons & Gordon-Salant, 1995), and sequence timing (Fitzgibbons & Gordon-Salant, 2001). Recent evidence (Grose et al., 2006) also indicates that the age-related decline in auditory temporal processing is evident by middle age. The ability to process brief acoustic cues is inherent in nearly every speech recognition task, but is stressed when speech materials are time compressed. Older listeners with and without hearing loss have inordinate difficulty accurately recognizing speech that is time compressed by 50% or more, particularly when few contextual cues are available in sentence-length speech materials (Wingfield et al., 1985; Gordon-Salant & Fitzgibbons, 1993). They also show poorer performance when only a phrase of a sentence is time-compressed, unlike younger listeners (Gordon-Salant & Fitzgibbons, 2004). This performance decline is ascribed, in part, to deficits in accurately perceiving the brief consonant phonemes in time-compressed speech (Gordon-Salant & Fitzgibbons, 2001) and in part to age-related slowing of information processing (Wingfield et al., 1985). Age-related declines in sequential working memory have been linked to deficits in recognition of time-compressed sentences with and without context (Vaughan et al., 2006). Moreover, older listeners show less tolerance than younger listeners for speech presented in noise when the speech is presented at increasing rates, reflecting the combined effects of reduced inhibition of distracting sounds and age-related slowing of information processing (Tun, 1998). Watching television, in which programming is often time compressed, can be particularly difficult for older listeners, although use of closed captioning significantly improves television viewing (Gordon-Salant & Callahan, 2009).

Other speech recognition paradigms have been utilized to reveal the importance of cognitive skills to speech understanding in less-than-ideal conditions. Older people retain their knowledge of the language to help them overcome some of the challenges to listening in poor acoustic environments. For example, recognition of speech in noise or time-compressed speech by older listeners approaches performance levels of younger listeners when contextual cues are available (Gordon-Salant & Fitzgibbons, 1997). In contrast, adding a memory task to the speech recognition task has a more adverse effect on performance by older than younger listeners (Pichora-Fuller et al., 1995), and requiring listeners to identify a target speech signal in the presence of dichotic or monotic competing speech signals with varying cues to target identity presents a more difficult task for older than younger listeners in divided attention but not selective attention conditions (Humes et al., 2006).

A more recent trend is to examine age effects in a dual-task paradigm in which recognition of speech is the primary task and a memory task for read materials (for example) is a secondary task (Gosselin & Gagne, 2010). Cognitive resources are limited at any moment in time and are often reduced in older people. In the dual-task paradigm, utilizing cognitive resources for one challenging task such as a memory task reduces the resources available for processing degraded or noisy speech. As a result, performance is consistently poorer for older than younger listeners. These types of challenges also require greater perceptual effort, which likely characterizes the impact of listening to speech in everyday challenging situations for older people with an impaired auditory system. In sum, older listeners have greater difficulty than younger listeners in accurately recognizing a message that is spoken at a fast rate or in noise, due in large part to reduced audibility of the speech signal, the consumption of cognitive resources during these challenging tasks, and the greater perceptual effort required to follow a distorted signal.

12.3.4 Training to Improve Speech Understanding

Individuals with high frequency sensorineural hearing loss, typical of presbycusis, experience difficulty detecting and discriminating acoustic cues that are important for distinguishing place of articulation (e.g., *pie* vs. *tie*). The talker's cues that are available on the face provide place of articulation information and thus are complementary to the cues that are provided acoustically. Investigations have confirmed the substantial benefit afforded by providing visual cues in addition to auditory cues for hearing-impaired listeners in noise (e.g., Bernstein & Grant, 2009), although the magnitude of the benefit may be reduced with age (Tye-Murray et al., 2010). Nevertheless, a key aspect of any training program is to increase awareness and encourage use of all supplemental cues that may be available, including visual and semantic contextual cues.

A rich literature is now emerging on the benefits of training for detection and discrimination of auditory signals on tasks of frequency discrimination, temporal-interval discrimination, AM rate discrimination, sound-source localization, and signal detection in noise (for a review, see Wright & Zhang, 2009). Many of the improvements in auditory abilities generalize to related signals and tasks. Tedious training to discriminate a single auditory cue may not be necessary; rather, exposure to the cue interspersed with a cue discrimination paradigm with feedback has been shown to produce significant improvements (Wright et al., 2010). The application of these types of training modules with older people has not yet been implemented systematically; however, the significant benefit and generalization of training in temporal-interval discrimination (Wright et al., 1997) may have specific implications for improving the auditory temporal processing abilities of older listeners. Some issues that may require refinement with the geriatric population are the time-course of learning, the generalization of learning, and fatigue.

12.4 Current and Future Directions

12.4.1 Demographics

Where should researchers focus their efforts to improve our understanding of the receptive communication problems of older people and translate this knowledge into effective rehabilitative techniques and technology to improve communication? How can we communicate better with our family and friends as we all grow older? Undoubtedly, changing demographics and lifestyles in our society dictate the imperative to examine the prevalence of different degrees of hearing loss, hearing aid use, benefit, and training for older people in the upper decades of life (80s, 90s, 100s!). Comparable data are lacking for middle-aged adults, although the onset of progressive age-related hearing loss and auditory processing deficits begins in middle age. Researchers must understand better the onset and natural progression of declines in auditory capabilities throughout the adult life span so that efforts to arrest further progression through training or use of sensory aids can be implemented at critical intervals. This approach is fundamental toward preventing the consequences if presbycusis as we know it today.

12.4.2 Speech Recognition Performance for Real-World Degraded Signals

Although a great deal is now known about speech recognition in noisy environments by older listeners with hearing loss (e.g., Humes & Dubno, 2010), very little is known about the difficulties these listeners encounter in perceiving speech altered by other forms of degradation encountered every day. These other forms of speech degradation (described below) are more subtle and may not be recognized as contributing to the listener's perceptual problems. Nevertheless, such signal alterations may contribute substantially to the limited benefit that older listeners report from hearing aids in real-world settings. In particular, because older listeners experience deficits in auditory temporal processing (Fitzgibbons & Gordon-Salant, 1996), it is likely that alterations in the temporal characteristics of speech signals have a substantial impact on speech intelligibility by this group.

One form of degraded speech that is prevalent in today's society is accented speech. Approximately 23 % of the population speaks a native language other than English; many of these speakers provide services to elderly individuals (Shin & Kominski, 2010). Alterations in the acoustic characteristics of English by accent vary with the native language of the talker, however, many of the alterations involve the duration of speech segmental cues especially in Spanish-accented English. Deficits in recognizing Spanish-accented English monosyllabic words by younger and older listeners are attributed to errors for consonant contrasts cued by timing information (Gordon-Salant et al., 2010a, b). Moreover, age-related differences in recognition of Spanish-accented English are particularly prominent in noise. The findings suggest that difficulties in understanding Spanish-accented English are primarily associated with poor perception of temporal information in consonants, especially by older listeners with hearing loss (Gordon-Salant et al., 2010a). In addition, differences in stress and timing are known to exist between native English and Spanish-accented English in part because Spanish is a syllable-timed language that is perceived with equal stress for each syllable, whereas English is a stress-timed language with equal time between stressed syllables. The impact of these deviations on older listeners' performance has not been investigated.

The typical cues used by listeners to separate a target talker from competing speech or noise and hence improve speech recognition may be compromised by talker accent, age, and hearing loss. In younger listeners with normal hearing, a background composed of broadband, modulated noise (i.e., energetic masking) produces less interference than a background of multiple talkers (i.e., energetic + informational masking) (Carhart et al., 1969). Similarly, listeners take advantage of differences in voice pitch and speech rate between the target talker vs. the competing speech masker (Brungart, 2001; Gordon-Salant & Fitzgibbons, 2004). The foregoing studies examined masking release for native English talkers (for the target and background speech). We recently investigated the use of these cues by younger and older listeners when the target and background talkers varied in English accent (Gordon-Salant et al., 2013). The hypothesis was that speech produced by native and Spanish-accented speakers of English could create a difference in relative timing between the target and background talkers; these timing differences potentially would serve as a cue to separate the target from the background. When the target talker was a native speaker of English, younger and older listeners with normal hearing were able to use a difference in accent between the target and background talkers to separate the two. However, listeners were unable to take advantage of any cues to speech segregation when the talker had a pronounced Spanish accent.

A tentative interpretation is that Spanish-accented English requires considerable effort to understand, and distracts listeners from taking advantage of typical cues for speech segregation.

Another form of alteration in the temporal cues in speech occurs with variations in talker rate, both across talkers and within the same talker. Most simulations of fast speech with time compression employed uniform time compression throughout the spoken message. However, talkers may vary the speed of their speech naturally even within a single sentence, for example, when they get excited or emphasize a point. Older listeners exhibit significant decline in recognition performance when a single phrase is time compressed, unlike younger listeners (Gordon-Salant & Fitzgibbons, 2004). Thus, older people are at a disadvantage in perceiving speech even when a brief segment of a message is spoken at a fast rate. Variations in natural speech rate between different talkers may contribute to some of the difficulties that older listeners with hearing loss report when participating in a group conversation. Sommers (1997) showed that trial-to-trial variations in talker rate produced significantly poorer performance among older hearing-impaired listeners than uniform talker rate, underscoring that older listeners with hearing loss have more difficulty in making moment-to-moment perceptual adjustments in this dimension. The Perceptually Robust English Sentence Test Open-Set (PRESTO) is composed of recordings by numerous talkers of both genders who speak with varying rates and dialects. These speech stimuli appear to be sensitive to the effects of aging and correlate with age-related cognitive decline (Pisoni et al., 2013). They may be particularly valuable to assess the impact of natural variations in talker speed on older hearing-impaired listeners' ability to process dynamically changing spoken materials.

12.4.3 Auditory–Visual Speech Perception

Real-world speech communication entails exposure to visual information as well as auditory information. The visual information may be supportive or detrimental to speech recognition, and hence may be viewed as providing a continuum of benefits and limitations. These benefits and limitations of visual information may be dependent on listener hearing status and age.

When the talker's face is visible, speech recognition in noise by hearing-impaired listeners improves dramatically because the speech information conveyed on the face is complementary to the speech information that is available through an impaired auditory system (Bernstein & Grant, 2009). Although older listeners benefit from the auditory + visual (AV) presentation of speech relative to A-only, they may not derive as much benefit as do younger listeners (Tye-Murray et al., 2010). This may be related, in part, to age-related decline in speechreading ability (Tye-Murray et al., 2007) or multimodal integration (Spehar et al., 2008).

Processing of AV stimuli may be compromised when there is asynchrony between the stimuli presented in the two modes. AV asynchrony is apparent in some television programs in which the auditory signal may lag or precede the presentation of the visual signal. Because older listeners show slowed auditory processing (Fitzgibbons & Gordon-Salant, 1996), it is possible that AV asynchrony is created for AV information or that preexisting asynchronous AV information is even more temporally mismatched among older people. Younger listeners exhibit a temporal window over which they can adequately integrate asynchronous AV speech information of −30 ms to +170 ms (re: auditory lag; van Wassenhove et al., 2007). There is no effect of age on the ability to *detect* asynchrony in AV stimuli (Başkent & Bazo, 2011), but recent pilot work in our lab (unpublished) suggests that aging affects the ability to *recognize* asynchronous AV speech signals and reduces the temporal integration window. Perception of accented asynchronous AV stimuli or asynchronous AV stimuli in noise may overwhelm the sensory, perceptual, and cognitive capacity of older hearing-impaired listeners, and could be a key factor underlying older listeners' difficulty following television programs, using hearing aids, or understanding accented speech.

One critical feature of nearly every communication setting that is taken for granted is the presence of visual information that is unrelated to the target speech message. For example, individuals' facial expressions while talking to others, a television program, and foot traffic as part of the visual scene can shift a listener's attention away from the primary communication task. As a result, these visual distracters may negatively impact speech recognition, particularly if the listener is monitoring information conveyed by the visual distracter (such as the latest baseball score on television). The addition of single visual distracters to auditory masking can decrease speech recognition performance by younger and older listeners with normal hearing (Gordon-Salant et al., 2011). However, the impact of visual distraction on the performance of older listeners with hearing loss or during a dual-task paradigm has not been investigated. Literature from auditory, cognitive, and visual neuroscience generally indicates that the ability to perform a target task in the presence of competing stimuli deteriorates with aging. This age-related decrease in performance appears to be related to decline in sensory and perceptual processes and their interaction with cognitive decline, suggesting that older hearing-impaired listeners will experience excessive difficulty in the presence of visual distraction. An understanding of the human and environmental factors that act to reduce the older listener's ability to parse relevant from irrelevant information in everyday auditory and visual scenes is fundamental to improving communication for this growing segment of the population.

12.4.4 Cognitive Load

The normal aging process entails a gradual and progressive decline in hearing sensitivity and cognitive abilities for most of us. The cognitive aging literature consistently shows that aging is accompanied by a decline in working memory (Baddeley, 1996), attention (Craik & Byrd, 1982), and speed of processing (Salthouse, 1996). The impact of specific dimensions of cognitive decline on auditory performance of older people in everyday communication situations is the subject of intense investigation.

It is reasonable to assume that listening to a spoken message distorted either by environmental conditions (noise), the talker (accent or rate), or the listener's hearing loss requires more cognitive resources to process the signal accurately. Given that an individual possesses a finite store of cognitive resources at any one moment in time and that some of these cognitive resources may be more limited in older than younger people, older listeners with hearing loss are expected to experience a greater cognitive load and hence may require greater listening effort to recognize speech in difficult listening conditions (Pichora-Fuller, 2003). Unfortunately, older listeners do not report greater cognitive load during increasingly difficult speech recognition tasks in noise (Larsby et al., 2005), perhaps reflecting an age-related bias toward underreporting communication problems.

A dual-task paradigm is a more objective technique to determine the impact of increased cognitive load on auditory performance. In this paradigm, performance for each single task is assessed, followed by performance in the two simultaneous tasks. The shift in performance on the primary task in the dual-task paradigm compared to the single-task paradigm indicates the impact of the additional cognitive load associated with the dual-task paradigm. Older participants perform much more poorly than younger listeners on a primary speech recognition task while also engaged in a secondary memory or pattern recognition task (Gosselin & Gagne, 2011). These results are interpreted as reflecting the reduced cognitive resources of older people that must be divided between the two tasks, under the assumption that there is a limited capacity of resources at any point in time.

12.4.5 New Directions for Hearing Aid Signal Processing

Directional microphones, noise-reduction algorithms, feedback management, digital programming, multichannel compression, and advanced connectivity to other communication devices are all remarkable advances that have been incorporated into contemporary hearing aids over the last decade. Laboratory studies indicate that older listeners with hearing loss benefit from amplification in quiet and steady-state noise conditions (Humes et al., 2002). Why, then, do older people with hearing loss largely reject them? The answer is undoubtedly multifactorial, including degree of hearing loss, personality factors, cost, appearance, etc. (Jenstad & Moon, 2011; Lin et al., 2011), but may also include perceived limited benefit of hearing aids in difficult communication situations. Although noise reduction algorithms attempt to attenuate the background noise, this is not accomplished easily if the background noise is composed of a speech signal that has comparable spectral and temporal properties as the target speech signal to be amplified. Another problem in successful use of hearing aids by older listeners is the combination of reduced spectral resolution, due to the sensorineural hearing loss, coupled with reduced auditory temporal processing associated with age. Souza and her colleagues (e.g., Souza, 2000) have confirmed that an age-related deficit in the use of temporal cues has an impact on older listeners' ability to process temporal-envelope cues in speech with compression amplification and/or across channels. These findings have critical implications for an older listener's success in perceiving hearing-aid processed speech in compression amplification conditions.

Current hearing aid signal processing algorithms do not alter the speech signal to accommodate the auditory temporal processing deficits of older listeners and the resulting difficulty in understanding rapid or variable-rate speech. One method that holds promise is to enhance selectively the duration of very brief consonants in ongoing (fast) speech (Gordon-Salant et al., 2007). However, significant time expansion of consonants may create asynchronous auditory and visual information. To rectify this potential asynchrony, it may be possible to compress the duration of vowels and pauses in natural speech while expanding the duration of consonants, as previous research has shown that selective time compression of vowels and pauses has little impact on performance (Gordon-Salant & Fitzgibbons, 2001). The implementation of this type of automatic signal processing method has yet to be developed.

12.4.6 New Models of Adaptation and Training

The established hierarchy of auditory training progresses from simple sound discrimination to more demanding complex speech identification paradigms, and forms the basis of traditional aural rehabilitation strategies. Principles of exposure, learning, and cognitive training have recently been applied to investigations of auditory learning and communication function (e.g., Wright & Zhang, 2009). For example, paradigms that present targeted acoustic cues to listeners with correct answer feedback interspersed with exposure to the same acoustic cues have been shown to promote auditory learning (Wright et al., 2010). Short-term exposure to accented English improves intelligibility accuracy and speed of processing for this type of distorted speech for younger listeners (Clarke & Garrett, 2004) and older listeners (Gordon-Salant et al., 2010c). Cognitive training paradigms focus on memory and speed of processing training; older listeners demonstrate significant gains in cognitive-specific measures but do not necessarily transfer improvements to functional activities (Ball et al., 2002). To date, the efficacy of these exclusively cognitive-based training paradigms for improving performance on auditory measures has not been reported.

The accessibility of home computers, videogames, and smartphones affords an unsurpassed opportunity to deliver auditory training paradigms easily to the end user. Indeed, several software programs and games have become widely available (e.g., LACE, Neurotone; Brain Fitness Program, Posit Science, etc.). A recent investigation by Anderson and her colleagues (Anderson et al., 2013) showed significant benefit of the Brain Fitness Program, which is a home-based computerized training program for older adults. The 40-hour training program, administered over the course of 8 weeks, emphasized auditory-based cognitive training, in which listeners discriminated slowed consonant–vowel (CV) syllables in isolation and various linguistic contexts; the CVs were compressed in duration as listeners exhibited performance improvement. Outcome measures demonstrated increments in sentence recognition in noise, improved memory and speed of processing, and faster neural timing, indicating that focused cognitive-auditory training has the potential to induce neural plasticity and reduce some of the speech understanding problems experienced by older people. Contemporary auditory training programs focus more on listening skills than cognitive skills, per se. One particularly promising program, the Speech Perception Assessment and Training System (SPATS; Miller et al., 2007), combines adaptive training with common speech syllable constituents (onsets, vowel nuclei, offsets) to sharpen spectrotemporal processing of specific syllabic segments, together with sentence-level training in which linguistic cues are stressed to improve bottom-up and top-down processing in quiet and noise. Initial evidence suggests that adults with hearing aids and cochlear implants gain significant benefit from SPATS training (Miller et al., 2008). An extensive multisite clinical trial to evaluate the efficacy of an intensive SPATS protocol for adult hearing aid users is currently underway.

Another relevant area of research derives from studies of the impact of long-term exposure to certain types of acoustic signals on signal processing and speech understanding. Long-term musical training has a significant benefit on speech recognition in noise as well as on latency and amplitude of auditory evoked potentials on matched groups of younger listeners with normal hearing (Parbery-Clark et al., 2009). Musical training also mitigates the expected decline in speech recognition performance in noise associated with aging (Parbery-Clark et al., 2012). Lifelong exposure to rapid speech appears to eliminate the expected age-related decline in recognizing time-compressed speech in quiet and in noise. For example, blind participants, who listen to recorded materials at fast playback rates for long periods of time, exhibit equivalent recognition scores for time-compressed speech as young listeners with comparable hearing sensitivity (Gordon-Salant & Friedman, 2011). Taken together, these findings suggest that age-related decline in speech recognition is not inevitable, and that significant experience with music and/or challenging speech materials can reduce or eliminate the problem. This type of long-term auditory training appears to require early and consistent implementation. Future investigations may be directed at the benefits of training at later stages of life and/or implementation during middle age as a form of prevention.

12.5 Summary

Research over the last 20 years has increased our understanding of the changes in the peripheral and central auditory nervous system that accompany the aging process and the import of these changes on functional communication in everyday settings. In addition to reduced audibility, older listeners exhibit deficits in auditory temporal processing that appear to limit the ability to understand rapid speech, accented speech (especially Spanish-accented English), and some forms of hearing-aid processed speech. Speech recognition in everyday face-to-face scenarios can be enhanced or diminished by the spectrum of visual information that is available in real-world settings. An analysis of the auditory and visual scene, as well as the sensitivity of older listeners with hearing loss to these varying AV cues, should be a priority in future investigations. Normal decline in working memory, speed of processing, selective attention, and other cognitive abilities also has a significant impact on speech recognition performance by older listeners in everyday challenging listening tasks, especially those involving dual simultaneous tasks.

Difficulty in hearing and understanding speech are not inevitable consequences of the aging process, however. Hearing aids do provide significant benefit to those with hearing loss, although signal processing adaptations for older listeners in certain conditions are still needed. Research has shown that lifestyle choices, implemented earlier in adulthood, can minimize some of the difficulties in speech understanding. Auditory, cognitive, and musical training, as well as exposure to rapid or accented speech stimuli all have the potential to improve communication function for seniors. The high prevalence rate of significant hearing loss among those older than 65 years coupled with the longer expected lifespan suggests that older people and their families will be seeking answers to the older listener's unique combination of auditory and cognitive deficits. It behooves researchers to identify and evaluate effective solutions aimed at our older hearing-impaired population, thereby enabling all of us to remain engaged and functioning members of society with the passage of time.

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