

# Age-Related Changes in Cognition and Speech Perception

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Aging is one of the most evident biological processes, but its mechanisms are still poorly understood. Studies of cognitive aging suggest that age is associated with cognitive decline; however, there may be individual differences such that not all older adults will experience cognitive decline. That is, cognitive decline is not intrinsic to aging, but there is some heterogeneity. Many researchers have shown that speech recognition declines with increasing age. Some of the age-related decline in speech perception can be accounted for by peripheral sensory problems but cognitive aging can also be a contributing factor. The potential sources of reduced recognition for rapid speech in the aged are reduction in processing time and reduction of the acoustic information in the signal. However, other studies also indicated that speech perception does not decline with age. Cognitive abilities are inherently involved in speech processing. Two cognitive factors that decline with age may influence speech perception performance. The first factor is working memory capacity and the second factor concerns the rate of information processing, defined generally as the speed at which an individual can extract content and construct meaning from a rapid signal. Cognitive function shows the adaptive processes with age which are consistent with the view that the brain itself has potentially a life-long capacity for neural plasticity. Assessing the speech perception difficulty in older adults, cognitive function could be considered in the evaluation and management of speech perception problem.

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## Introduction

Aging is one of the most evident biological processes whose molecular and cellular mechanisms are still poorly understood. Age-related changes involve almost all aspects of human beings such as the brain, bones, joints, eyes, ears, digestive, metabolic, urogenital, dental system, skin and functional abilities.

Regarding the bones and joints, the weight-bearing bones and the movable joints take much wear and tear as the body ages. Consequently, osteoporosis and arthritis occur commonly among older adults. Likewise, there are age-related changes in the brain; however, still much is not known about age-related changes in the brain.

Among brain functions, cognitive function and speech perception abilities seem to be affected by aging. There is still no consensus about the mechanisms underlying cognition and speech perception problems in the aged. Changes in hearing

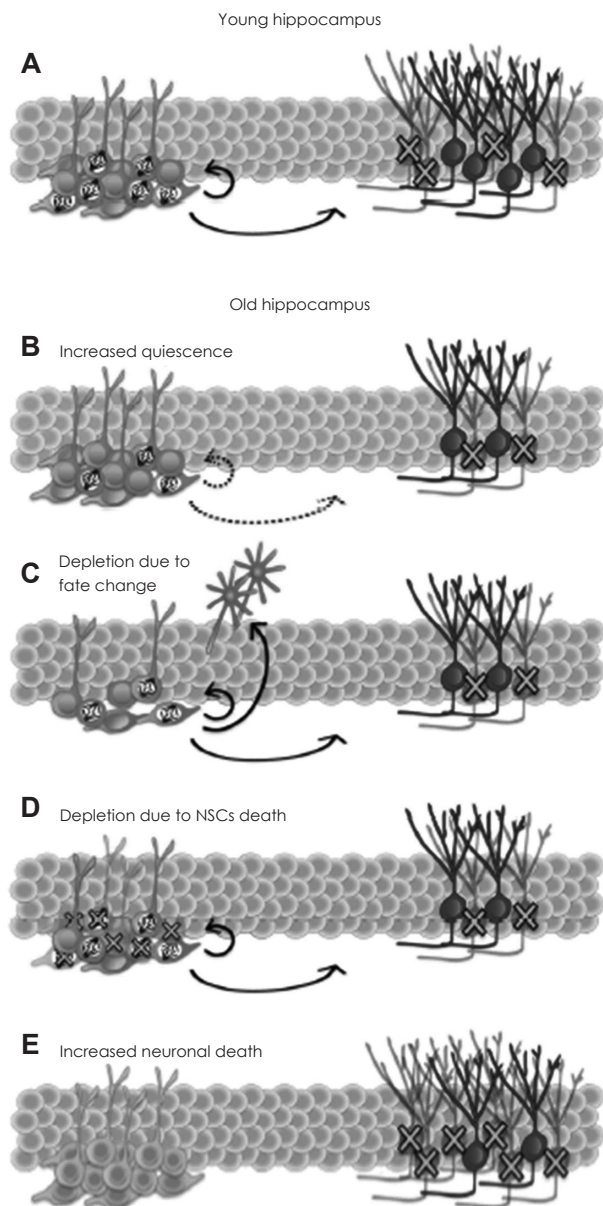
thresholds, memory, attention, and speed of processing all could be causes of the difficulties older adults encounter in everyday life.<sup>1-3)</sup>

The objective of this article is to review age-related changes in cognition and speech perception and to investigate their interrelationship. In addition, this study will provide a current understanding of the mechanism of age-related decline in cognition and speech perception.

## Cognition: Association with Aging

Cognitive function is broadly defined as an intellectual process by which one becomes aware of, perceives, or comprehends ideas. It involves all aspects of perception, thinking, reasoning, and remembering.

Studies of cognitive aging suggest that age is associated with cognitive decline. The average course of cognitive abilities over the last several decades of life is accelerating decline.<sup>4)</sup> This



**Fig. 1.** Potential mechanisms responsible for age-related decline in neurogenesis (Adapted from Benedetta A, et al. Aging 2012, according to the Creative Commons license). Proliferating and quiescent neural stem and progenitor cells (NSCs; left column) are indicated by the presence or lack of mitotic spindles, respectively. Proliferating NSCs divide to generate (arrows) additional NSCs or immature neurons (right column). During maturation, many neurons undergo apoptosis (crosses). A: Schematic representation of adult neurogenesis in the young hippocampus. B–E: Schematic representation of adult neurogenesis in the senescent hippocampus. A reduced number of neurons in the senescent hippocampus (B–E) can be explained by an increase in quiescence i.e. a lower proportion of proliferating NSCs (B), a change in NSCs fate i.e. an increase in differentiation at the expense of proliferative and/or gliogenic at the expense of neurogenic division (C), depletion of NSCs by cell death (D), or a higher proportion of newborn neurons undergoing apoptosis (E). Continuous or dashed arrows (A–D) indicate a constant number or decreases in the proportion of proliferating NSCs and neurons generated from the total pool of NSCs, respectively.

phenomenon is shown in cross-sectional, longitudinal studies, and studies on neural stem cells.<sup>5)</sup>

Growing evidence indicates that a few types of resident neural stem cells (NSCs) that are located in specific brain regions, most notably the subgranular zone of the hippocampus, seem to play a major role in cognitive functions such as learning, memory, and emotional behavior.<sup>6,7)</sup> A possible mechanism of age-related changes in neurogenesis is introduced (Fig. 1).<sup>5)</sup>

Aging constitutes one of the major factors reducing the proliferation of NSCs,<sup>8,9)</sup> while cognitive decline, including reduced learning and memory performance, is commonly observed in aged individuals.<sup>9,10)</sup>

Manipulations that decrease neurogenesis typically worsen cognitive performance in senescent animals while, conversely, an increase in neurogenesis tends to improve learning and memory.<sup>11,12)</sup>

However, some studies indicate that cognitive decline is not intrinsic to aging, but there is some heterogeneity.<sup>13,14)</sup> According to a recent study, cognitive decline is not a normal part of aging and is associated with some form of neuropathology.<sup>15)</sup> In the study, individuals were classified into 3 groups by three different rates of decline: slow, moderate, and fast. Individuals in the fast decline groups had high levels of amyloid plaques and neurofibrillary tangles. On the other hand, individuals in the slow decline class had the least amount of neuropathology.

Therefore, there is still controversy as to whether aging and cognitive decline are associated, and there may be individual differences such that not all older adults will experience cognitive decline.

## Speech Perception: Association with Aging

Speech perception is the process by which the sounds of language are heard, interpreted and understood. In general, older adults complain that talkers seem to mumble or talk too fast and that it is hard to hear when there is background noise. Many researchers have shown that speech recognition declines with increasing age.<sup>16,17)</sup> According to one report, as many as one-third of seniors find it difficult to understand conversations in everyday listening situations.<sup>18)</sup>

Age-related difficulties in speech understanding may be attributed to changes in higher-level cognitive processes such as language comprehension, memory, attention, and cognitive slowing, or to lower-level sensory and perceptual processes.<sup>19)</sup> That is, some of the age-related decline in speech perception can be accounted for by peripheral sensory problems, but cognitive aging can also be a contributing factor.<sup>20)</sup>

Many studies of speech recognition in older adults report

age-related differences in performance. However, the interpretation of decreased speech perception in older adults is complicated by the change in pure-tone thresholds that occurs with increasing age.

Age-related peripheral hearing loss, called presbycusis, is highly prevalent and hearing loss in older adults is associated with a number of pathologies. Among them, strial degeneration is assumed to be the dominant cause of presbycusis.<sup>21)</sup>

The effects of age-related decline in hearing thresholds on speech perception have been extensively studied. The finding is that high-frequency threshold hearing loss accounts for much of the loss of phonetic information and word identification in quiet listening conditions.<sup>22,23)</sup>

In addition to the decline in hearing threshold, older adults show a greater reduction in speech recognition than younger adults, with increasing speech rate.<sup>24)</sup> The potential sources of reduced recognition for rapid speech are reduction in processing time and reduction of the acoustic information in the signal.

However, other many studies also indicated that speech perception does not decline with age, after correcting for the effects of different hearing thresholds.<sup>25)</sup> In some cross-sectional studies, pure-tone thresholds that change with increasing age and rates of change that vary among individuals are factors that complicate the interpretation of the differing levels of speech perception in older adults. In one study, when thresholds across age groups were equated, speech perception did not differ from age 50 to age 90, except for the Synthetic Sentence Identification.<sup>26)</sup> In other study, no significant differences were found in speech recognition for individuals in three age groups: 55–64, 65–74, and 75–84 years who were selected so that the average pure-tone thresholds for the three groups were within 5 dB of each other.<sup>27)</sup>

According to a longitudinal study, age-related decline in word recognition was more consistent with underlying changes in auditory function, rather than decline in cognitive function, as a result of peripheral, rather than central, system pathology.<sup>28)</sup>

## Analysis of Characteristics of Auditory Aging

Fast speech rate and the presence of background noise disrupt word identification more for older than younger listeners even when their pure-tone thresholds are normal.<sup>16,27,29,30)</sup>

Some changes in auditory processing are assumed to give rise to the particular vulnerabilities of older listeners when speech is heard with background noise or at fast rates. Those changes include declines in monoaural auditory temporal pro-

cessing,<sup>31)</sup> binaural processing,<sup>32)</sup> and behavioral and physiological factors in auditory temporal processing.<sup>31,33)</sup>

Gap detection thresholds are higher for older adults, potentially reducing temporal segregation of events. That is, older adults do not detect a gap in the signal until the size of the gap is about twice as large as the smallest gap detectable by younger adults (approximately 6 ms vs. 3 ms).<sup>34)</sup> Gap detection thresholds are not predictable from pure-tone hearing thresholds in listeners with normal audiograms.<sup>35,36)</sup>

## The Relationship between Cognition and Speech Perception

Cognitive abilities are inherently involved in speech perception and they are highly correlated. Some studies suggested the importance of cognitive function, in addition to hearing factors, that limit speech perception among older adults.<sup>37)</sup> On the other hand, some studies reported that the effect of cognitive decline on the speech perception performance of older adults is not significant.<sup>22)</sup> Cognitive function is not composed of a single component but is composed of many distinct components such as attention, memory, and language comprehension.

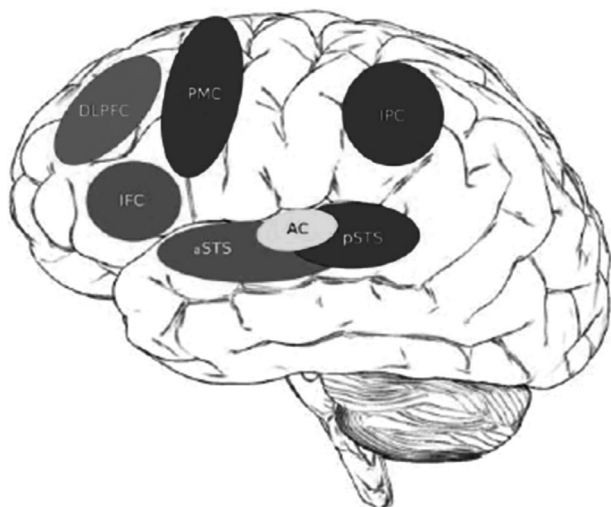
Considering the cognitive components specific to speech perception, two cognitive factors that decline with age may influence speech perception performance. Those two factors are working memory capacity and the rate of information processing that is defined generally as the speed at which an individual can extract content and construct meaning from a rapid signal.<sup>3,38)</sup>

Working memory refers to a temporary short-term store where information is held and related to later-occurring events. Cohen<sup>39)</sup> (1987) noted that working memory capacity could affect speech understanding because parts of the spoken message must be retained in the memory and related to later parts of the message for the comprehension of logical relationships between words and concepts. Working memory is known to decline minimally with aging.<sup>40)</sup>

According to one study, age-related decline in auditory processing, rather than changes in the capacity of the working memory, primarily influences speech perception,<sup>2)</sup> and reduction in the available processing time causes reduced recognition for older adults.<sup>25)</sup> Therefore, older adults tend to have difficulties in speech perception with rapid speech.

## Brain Systems: Integrating Auditory and Cognitive Information

Davis and Silverman<sup>41)</sup> (1970) recognized long ago how brain systems integrate auditory and cognitive information



**Fig. 2.** Brain regions involved in speech processing in older age (Adapted from Aydelott, et al. Trends in Amplification 2011, with permission from SAGE). Schematic highlights in the left cortical regions involved in speech perception. Antero-ventral (aSTS) and postero-dorsal (pSTS) auditory streams originate from the primary auditory cortices (AC), auditory belt/Heschl's gyrus. The postero-dorsal stream interfaces with the premotor areas and pivots around the inferior parietal cortex (IPC). Object information, such as mapping speech onto semantics, is decoded in the antero-ventral stream to the inferior frontal cortex (IFC; Brodmann's area 44, 45). In the postero-dorsal route, attention- or intention-related changes in the inferior parietal lobule (IPL; Brodmann's area 40) influence the selection of context-dependent action programs in prefrontal cortex and premotor cortex (PMC; Brodmann's area 6) areas. Both routes can be modulated by activity in the dorsolateral prefrontal cortices (PLPFC; Brodmann's area 9, 46). STS: superior temporal sulcus, IFC: inferior frontal cortex, IPL: inferior parietal lobule, DLPFC: dorsolateral prefrontal cortical.

would be crucial to our understanding of speech communication.

Acoustic analysis of the information occurs in the middorsal superior temporal region then proceeds either anteriorly along the superior temporal gyrus (STG) to the inferior frontal cortices in mapping speech to meaning or posteriorly along the STG to the inferior parietal lobe and then to the premotor cortices (Fig. 2).<sup>42)</sup> Left dorsolateral prefrontal cortical areas are thought to be involved in semantic processing and working memory. PFC activation is particularly important in the aged<sup>43)</sup> as it is supposed to be a reflection of recruitment of more working memory resources.<sup>40)</sup>

## Decline-Compensation Hypothesis

Cognitive aging involves a combination of decline in sensory processing and a following increase in the recruitment of more general cognitive areas such as the PFC, as a means of compensation.<sup>20)</sup>

For example, when younger and older adults perform equivalently on various perceptual and cognitive tasks, there is more

widespread activation in older brains than in younger brains, with one interpretation being that this reflects compensatory processing in older adults.<sup>43)</sup>

These findings that correlate adaptive cognitive processes with age are consistent with the concept that the brain itself has potentially a life-long capacity for neural plasticity and adaptive reorganization.<sup>20)</sup>

## Value of Cognitive Function Testing for the Evaluation of Speech Perception in the Aged

Aging affects both the peripheral and central auditory system. Simply evaluating the peripheral auditory system is not enough to fully understand the pathophysiology of impaired speech perception in older adults. Therefore, diagnostic evaluation for speech perception difficulty in older adults should not only include standard audiometric testing, but also include measures of central auditory function and related cognitive functions. Tests of cognitive function could also be used as sensitive outcome measures of hearing rehabilitation.<sup>44)</sup> Likewise, regarding the management of speech perception problems in older adults, treatment aimed at compensating only for the peripheral auditory impairment is inadequate, but it might still be better to include this strategy to compensate for central auditory impairment and cognitive function deficits.

## Conclusion

The effect of age on speech perception and cognitive processing is not well understood. Although there is still controversy as to whether cognitive function and speech perception decline with age, in general, older adults have difficulty in everyday communication whether the cause is in the peripheral hearing system or in the central cognitive system. Hearing becomes more difficult with age but brain plasticity and cognitive function might continue to compensate for the peripheral impairment. Therefore, cognitive function testing could also be considered in the evaluation of speech perception especially for the aged and there is significance for adopting central auditory rehabilitation training for the aged. Further studies should be performed to delineate which cognitive skills are more sensitive in the perception of speech.

## REFERENCES

- 1) Patterson RD, Nimmo-Smith I, Weber DL, Milroy R. The deterioration of hearing with age: frequency selectivity, the critical ratio, the audiogram, and speech threshold. *J Acoust Soc Am* 1982;72:1788-

- 803.
- 2) Pichora-Fuller MK, Schneider BA, Daneman M. How young and old adults listen to and remember speech in noise. *J Acoust Soc Am* 1995;97:593-608.
  - 3) Salthouse TA. The processing-speed theory of adult age differences in cognition. *Psychol Rev* 1996;103:403-28.
  - 4) Verhaeghen P, Salthouse TA. Meta-analyses of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models. *Psychol Bull* 1997;122:231-49.
  - 5) Artegiani B, Calegari F. Age-related cognitive decline: can neural stem cells help us? *Aging (Albany NY)* 2012;4:176-86.
  - 6) Yassa MA, Stark CE. Pattern separation in the hippocampus. *Trends Neurosci* 2011;34:515-25.
  - 7) Deng W, Aimone JB, Gage FH. New neurons and new memories: how does adult hippocampal neurogenesis affect learning and memory? *Nat Rev Neurosci* 2010;11:339-50.
  - 8) Altman J, Das GD. Autoradiographic and histological evidence of postnatal hippocampal neurogenesis in rats. *J Comp Neurol* 1965; 124:319-35.
  - 9) Kuhn HG, Dickinson-Anson H, Gage FH. Neurogenesis in the dentate gyrus of the adult rat: age-related decrease of neuronal progenitor proliferation. *J Neurosci* 1996;16:2027-33.
  - 10) Gage FH, Kelly PA, Björklund A. Regional changes in brain glucose metabolism reflect cognitive impairments in aged rats. *J Neurosci* 1984;4:2856-65.
  - 11) Montaron MF, Drapeau E, Dupret D, Kitchener P, Arousseau C, Le Moal M, et al. Lifelong corticosterone level determines age-related decline in neurogenesis and memory. *Neurobiol Aging* 2006; 27:645-54.
  - 12) Kempermann G, Kuhn HG, Gage FH. Experience-induced neurogenesis in the senescent dentate gyrus. *J Neurosci* 1998;18:3206-12.
  - 13) Wilson RS, Beckett LA, Barnes LL, Schneider JA, Bach J, Evans DA, et al. Individual differences in rates of change in cognitive abilities of older persons. *Psychol Aging* 2002;17:179-93.
  - 14) Christensen H, Jorm AF, Henderson AS, Mackinnon AJ, Korten AE, Scott LR. The relationship between health and cognitive functioning in a sample of elderly people in the community. *Age Ageing* 1994;23:204-12.
  - 15) Hayden KM, Reed BR, Manly JJ, Tommet D, Pietrzak RH, Chelune GJ, et al. Cognitive decline in the elderly: an analysis of population heterogeneity. *Age Ageing* 2011;40:684-9.
  - 16) Cheesman MF, Hepburn D, Armitage JC, Marshall K. Comparison of growth of masking functions and speech discrimination abilities in younger and older adults. *Audiology* 1995;34:321-33.
  - 17) Divenyi PL, Haupt KM. Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss. I. Age and lateral asymmetry effects. *Ear Hear* 1997;18:42-61.
  - 18) Hamilton-Wentworth District Health Council. Services for seniors study: Report of findings and recommendations. Hamilton, ON: Regional Municipality of Hamilton-Wentworth & Hamilton-Wentworth District Health Council;1988.
  - 19) Schneider BA, Daneman M, Pichora-Fuller MK. Listening in aging adults: from discourse comprehension to psychoacoustics. *Can J Exp Psychol* 2002;56:139-52.
  - 20) Aydelott J, Leech R, Crinion J. Normal adult aging and the contextual influences affecting speech and meaningful sound perception. *Trends Amplif* 2010;14:218-32.
  - 21) Gates GA, Mills JH. Presbycusis. *Lancet* 2005;366:1111-20.
  - 22) Humes LE. Speech understanding in the elderly. *J Am Acad Audiol* 1996;7:161-7.
  - 23) van Rooij JC, Plomp R. Auditive and cognitive factors in speech perception by elderly listeners. III. Additional data and final discussion. *J Acoust Soc Am* 1992;91:1028-33.
  - 24) Gordon-Salant S, Fitzgibbons PJ. Effects of stimulus and noise rate variability on speech perception by younger and older adults. *J Acoust Soc Am* 2004;115:1808-17.
  - 25) Jenstad LM, Souza PE. Temporal envelope changes of compression and speech rate: combined effects on recognition for older adults. *J Speech Lang Hear Res* 2007;50:1123-38.
  - 26) Jerger J. Can age-related decline in speech understanding be explained by peripheral hearing loss? *J Am Acad Audiol* 1992;3:33-8.
  - 27) Dubno JR, Lee FS, Matthews LJ, Mills JH. Age-related and gender-related changes in monaural speech recognition. *J Speech Lang Hear Res* 1997;40:444-52.
  - 28) Dubno JR, Lee FS, Matthews LJ, Ahlstrom JB, Horwitz AR, Mills JH. Longitudinal changes in speech recognition in older persons. *J Acoust Soc Am* 2008;123:462-75.
  - 29) Wingfield A, Ducharme JL. Effects of age and passage difficulty on listening-rate preferences for time-altered speech. *J Gerontol B Psychol Sci Soc Sci* 1999;54:P199-202.
  - 30) Wingfield A. Cognitive factors in auditory performance: context, speed of processing, and constraints of memory. *J Am Acad Audiol* 1996;7:175-82.
  - 31) Fitzgibbons PJ, Gordon-Salant S. Auditory temporal processing in elderly listeners. *J Am Acad Audiol* 1996;7:183-9.
  - 32) Grose JH. Binaural performance and aging. *J Am Acad Audiol* 1996; 7:168-74.
  - 33) Frisina DR, Frisina RD. Speech recognition in noise and presbycusis: relations to possible neural mechanisms. *Hear Res* 1997;106:95-104.
  - 34) Heinrich A, Schneider B. Age-related changes in within- and between-channel gap detection using sinusoidal stimuli. *J Acoust Soc Am* 2006;119:2316-26.
  - 35) Gordon NC, Heller PH, Gear RW, Levine JD. Temporal factors in the enhancement of morphine analgesia by desipramine. *Pain* 1993; 53:273-6.
  - 36) Strouse A, Ashmead DH, Ohde RN, Grantham DW. Temporal processing in the aging auditory system. *J Acoust Soc Am* 1998;104:2385-99.
  - 37) Jerger J, Jerger S, Oliver T, Pirozzolo F. Speech understanding in the elderly. *Ear Hear* 1989;10:79-89.
  - 38) Bialystok E, Craik F, Luk G. Cognitive control and lexical access in younger and older bilinguals. *J Exp Psychol Learn Mem Cogn* 2008;34:859-73.
  - 39) Cohen G. Speech comprehension in the elderly: the effects of cognitive changes. *Br J Audiol* 1987;21:221-6.
  - 40) Just MA, Carpenter PA. A capacity theory of comprehension: individual differences in working memory. *Psychol Rev* 1992;99:122-49.
  - 41) Davis H, Silverman R. Hearing and deafness. 3rd ed. New York, NY: Holt, Rinehart, Winston;1970.
  - 42) Hickok G, Poeppel D. Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. *Cognition* 2004;92:67-99.
  - 43) Cabeza R, Anderson ND, Locantore JK, McIntosh AR. Aging gracefully: compensatory brain activity in high-performing older adults. *Neuroimage* 2002;17:1394-402.
  - 44) Lehl S, Funk R, Seifert K. [The first hearing aid increases mental capacity. Open controlled clinical trial as a pilot study]. *HNO* 2005; 53:852-62.