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Research Forum

Speech Recognition Across the Life Span: Longitudinal Changes From Middle-Age to Older Adults

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Purpose: The purpose of this article is to provide an overview of evidence of age-related declines in speech recognition in middle age to older adulthood; to review contributions of pure-tone thresholds, age, and gender; and to report preliminary results from a longitudinal study.

Method: Pure-tone thresholds and word recognition in quiet and babble are being measured in a large sample of adults yearly or every 2 to 3 years. Analyses included >16,000 audiograms and speech recognition scores from >1,200 adults whose ages ranged from the 40s to the 90s. A multivariable generalized linear repeated mixed model assessed changes in thresholds and speech recognition over time.

Results: Word recognition in quiet declined significantly while controlling for threshold increases, and declines appeared to accelerate near ages 65 to 70 years. Scores for men were poorer than those for women even after controlling for gender differences in thresholds, but rates of decline did not differ by gender. Smaller declines in key word recognition in babble were observed, and declines appeared to accelerate near ages 75 to 80 years.

Conclusions: Additional evidence is needed from large-scale longitudinal cohort studies to determine rates of change of auditory function across the life span. These studies can identify associations with modifiable risk factors and potential mechanisms to reduce, to prevent, or to delay the onset of age-related hearing loss.

Damaging effects to the auditory periphery from a lifetime of environmental exposures and disease processes, coupled with naturally occurring age-related changes to the periphery, can lead to anatomic, physiologic, and neurochemical deficits in the aging auditory system. These deficits can result in a wide range of changes in auditory abilities, including reduced detection for low-level signals (hearing loss) and impaired function for higher-level signals, such as declines in complex signal processing and speech understanding, especially in noisy and other challenging conditions. Thus, the auditory periphery delivers degraded signal representations for processing by aging central auditory pathways and cortex. At the same time, declines in cognitive function may be occurring, such as in working memory, executive function, attention, and processing speed. These effects may impose increased demands on an aging brain with already limited resources and loss of inhibition.

In addition to complexities related to these multiple sites of impairment, multiple risk factors for the aging auditory system have been identified. These include various aging processes, accumulated effects of environmental exposures such as excessive noise or ototoxic drugs, and certain disease process and comorbid conditions. In animal models of age-related hearing loss, laboratory animals are raised in controlled environments wherein noise levels are low and drugs, diet, nutrition, and disease are carefully monitored. Thus, any pathological changes in the auditory system and any functional changes observed in older animals relate only to the aging process. In older humans, it is difficult to disentangle these multiple effects to allocate portions of the measured hearing loss to each risk factor and develop strategies to prevent or delay the onset of age-related declines.

Several large-scale cross-sectional studies of speech recognition have been conducted with the goal of quantifying these age-related changes across the life span. In cross-sectional studies (e.g., Dubno, Lee, Matthews, & Mills, 1997; Gates, Cooper, Kannel, & Miller, 1990; Jerger, 1973, 1990, 1992; Mościcki, Elkins, Baum, & McNamara, 1985; Wiley et al., 1998), differences in speech recognition are determined for large numbers of participants grouped

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according to age. Results have been mixed and difficult to interpret because pure-tone thresholds and other factors also increase with age, and rates of change vary among individuals and may differ for men and women (Dubno et al., 2008). Inconsistent results from cross-sectional studies may also be attributed to cohort effects, which can introduce confounding factors.

For several reasons, large-scale longitudinal studies of speech recognition are the preferred design for identifying risk factors and estimating age-related changes and interactions. In a longitudinal study, speech recognition in each individual is assessed using the same measures several times over many years or even decades. In this way, participants act as their own controls, which minimizes the effects of uncontrollable factors, such as variations among individuals in occupation, health conditions, and nutrition. Cross-sectional studies typically focus on group effects, whereas longitudinal studies can measure age-related changes for groups and individuals. Of course, lengthy data collection in longitudinal studies is more costly and requires a long-term commitment of participants in good overall health. As a result, these studies may tend to retain older adults who are in better overall health or are higher performing than the general aging population.

Perhaps for some of these reasons, very few large-scale longitudinal studies of speech recognition in older persons have been conducted, and even fewer included measures of speech recognition in noise (Bergman et al., 1976; Hietanen, Era, Sorri, & Heikkinen, 2004; Møller, 1981; Pedersen, Rosenhall, & Møilerb, 1991). Study limitations included small sample sizes, non-population-based samples, narrow age ranges (not including middle age), and short follow-up periods. Most important, not all studies controlled for effect of age-related declines in detection thresholds (Divenyi, Stark, & Haupt, 2005, is an exception). Although there have been several large-scale longitudinal studies of hearing and some included measures of speech recognition (e.g., Brant & Fozard, 1990; Cruickshanks et al., 2003; Davis, Ostri, & Parving, 1991; Gates & Cooper, 1991; Pearson et al., 1995), none reported longitudinal changes.

Pronk et al. (2013) recently analyzed results from 1,298 participants (ages 57–93 years) from the community-based Longitudinal Aging Study of Amsterdam (Huisman et al., 2011) for a digit triplet speech-in-noise task to determine (a) if rates of change in speech recognition in noise over time differ across age and gender and (b) the role of health, environmental, and cognitive factors. Speech reception thresholds in noise measured over a 3- to 7-year period increased by 0.18 dB/year overall, and these rates increased systematically with age (ranging from 0.13 to 0.27 dB/year across four decade ranges). Only processing speed was found to be a significant, but moderate, predictor of rate of change. Pure-tone thresholds measured in conjunction with speech recognition were unfortunately not available. Therefore, it remains unclear the extent to which observed age-related declines in speech recognition in noise relate to reductions in speech audibility that occurred over the same time period due to increasing detection thresholds.

Longitudinal Study of Age-Related Hearing Loss

In the longitudinal study of age-related hearing loss at the Medical University of South Carolina that began in 1988, measures of peripheral and central auditory function are administered yearly or every 2 to 3 years and include detection of pure tones (0.25–8.00 kHz), detection of high frequencies (10–18 kHz), middle ear function, cochlear function (otoacoustic emissions and masked thresholds), auditory brainstem responses, and measures of speech recognition (in quiet and in noise; with single words and sentences; and monaural and binaural). In addition, participants complete questionnaires on hearing and medical health, use of prescription and over-the-counter drugs, and self-assessed hearing handicap, among others. A cognitive test battery includes measures of attention, working memory, processing speed, and perceived workload. Blood is drawn for clinical chemistries and to extract and store DNA. Participants are 18 years and older, in good general health, and have no restrictions on hearing levels except the requirement to provide measureable results. The Medical University of South Carolina human subject database currently includes data from approximately 1,500 participants; 50 to 100 new participants are recruited each year to maintain approximately 450 active participants. An initial analysis of 256 participants aged 55 years and older from this cohort (Dubno et al., 2008) used linear regression slopes to estimate rates of changes in speech recognition scores adjusted using an importance-weighted speech audibility metric to control for concurrent changes in pure-tone thresholds and speech levels. Results revealed that declines in speech recognition in quiet over time at older ages were greater than predicted from increases in detection thresholds over the same time period. The current analysis of longitudinal changes in speech recognition for middle-aged and older adults includes approximately 1,250 participants ranging in age from 40 to 96 years (mean = approximately 67 years; approximately 55% women and 45% men; approximately 27% racial or ethnic minorities).

Longitudinal Changes in Pure-Tone Thresholds

To assess changes in pure-tone thresholds over time, a multivariable generalized linear repeated mixed model was used (SAS Version 9.3, Cary, NC; West, Welch, & Galecki, 2007). This procedure accounts for correlations over time within participants and allows for different numbers of repeated measures, so all thresholds contribute (i.e., no missing cases). Gender and ear were added to the model as covariates. The current analysis includes approximately 16,000 audiograms from approximately 2,400 ears. Preliminary results revealed that thresholds were poorer for men than for women at higher frequencies. Audiometric configurations were consistent with a mostly metabolic phenotype for women, related to reduced endocochlear potential and cochlear amplifier gain, but mostly sensory or metabolic and sensory phenotypes for men (Dubno, Eckert, Lee, Matthews, & Schmiedt, 2013). Rates of threshold increases averaged 0.4 to 0.8 dB/year, with faster rates of increase for men than for women from 2.0 to 8.0 kHz. Slower overall rates of threshold increase for this sample (<1.0 dB/year; Lee, Matthews, Dubno, & Mills, 2005) may reflect inclusion of middle-aged adults, although mean ages were similar in the two cohorts.

Longitudinal Changes in Speech Recognition in Quiet and in Babble

Word recognition in quiet was assessed monaurally in the right and left ears with Northwestern University Auditory Test No. 6 monosyllabic consonant–vowel–consonant words (Tillman & Carhart, 1966) presented at 30 to 40 dB above the speech recognition threshold. Scores were obtained at each laboratory visit (yearly or more often). The current analysis includes approximately 16,000 scores (corresponding to the approximately 16,000 audiograms mentioned earlier) obtained during one to 28 laboratory visits over a span of 0 to 25 years. Key word recognition in babble was assessed with the Speech Perception in Noise Test and 12-talker babble (Kalikow, Stevens, & Elliott, 1977) using a +8 dB signal-to-noise ratio. Scores for Speech Perception in Noise Test high-context and low-context sentences were obtained every 2 to 3 years, yielding fewer scores than for word recognition in quiet. Thus, the current analysis includes approximately 3,600 scores from approximately 1,800 ears obtained during one to eight laboratory visits over a span of 0 to 23 years. To assess changes in speech recognition over time, the same analysis procedure was used as for pure-tone thresholds (SAS Version 9.3). Covariates also accounted for unique effects of changes over time in pure-tone thresholds (0.25–4.00 kHz), speech levels, and participant age.

Preliminary analyses revealed that, for each year of aging, word recognition in quiet declined by approximately 1.3 rau (13 rau/decade), but while controlling for threshold increases over the same period, scores declined significantly by only approximately 0.3 rau/year (3 rau/decade); declines appeared to accelerate near ages 65 to 70 years. Although scores in quiet for men were poorer than those for women even after controlling for gender differences in thresholds, rates of decline did not differ by gender. While controlling for threshold increases, even smaller but still significant declines in key word recognition in babble were observed for low-context sentences. Similar declines were observed for high-context sentences, but for men only; declines appeared to accelerate near age 75 to 80 years. A notable result was the relatively large portion of speech recognition declines over time that was attributable to threshold changes. Each dB increase in threshold over time contributed approximately 0.1 to 0.5 rau to the decline in score over time, with threshold increases at 2.0 kHz serving as the largest contributor.

Summary and Conclusions

Preliminary analyses showed that word recognition in quiet declines with age, even after accounting for reductions in audible speech due to poorer hearing. Rates of decline were similar for men and women, but scores were poorer for men, which may relate to differences in etiology (metabolic vs. sensory phenotypes for women vs. men). Key word recognition of sentences in babble declined slightly or remained constant with increasing age, with no gender differences. Key word recognition in sentences was preserved to older age more than monosyllabic word recognition in quiet. Threshold increases with age were large contributors to speech recognition declines, especially at 2.0 kHz, and were larger than contributions of age alone. With regard to gender differences, questions remain about whether observed differences in thresholds and speech recognition are a social or biological construct. That is, are these effects attributed to gender-related differences in environmental exposures, which lead to differences in age-related pathologies? Or are they attributed to underlying gender-related neurobiological mechanisms? Although the answers are unclear, gender remains a useful clinical marker for the consequences of age-related hearing loss.

Analyses are ongoing and include as covariates audiometric phenotype, environmental factors (noise, drug exposures), demographic factors, and health conditions. In addition, longitudinal changes in binaural speech recognition (using the Staggered Spondaic Word Test; Katz, 1962) are being evaluated and compared with results for monaural tasks. Further exploration is also being conducted of the mid-60s acceleration of speech recognition declines in quiet and the mid-70s acceleration of speech recognition declines in babble.

These results, and those from other longitudinal studies of hearing—for example, the Beaver Dam Epidemiology of Hearing Loss Study (Cruickshanks et al., 2003), the Beaver Dam Offspring Study (Nash et al., 2011), the Blue Mountains Hearing Study of Older Australians (Mitchell et al., 2011), and the Nurses' Health Study's Conservation of Hearing Study (Curhan, 2015)—highlight the need for additional evidence of the magnitude of changes in auditory function across the life span. Large-scale longitudinal cohort studies can identify associations with modifiable risk factors and potential mechanisms to reduce, prevent, or delay the onset of age-related hearing loss.

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