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Effects of Age and High Frequency Hearing Loss on Binaural Speech Understanding Using HINT Study

SungHee Kim*, Robert D. Frisina**, Susan T. Frisina***, Frances M Mapes***,
Elizabeth D. Hickman***, D. Robert Frisina***
*Dep. of Otolaryngology, Daegu Fatima hospital, Daegu, Korea
**Dep. of Otolaryngology, University of Rochester Medical Center, Rochester, NY, USA
***International Center for Hearing and Speech Research, National Institute for the Deaf, Rochester Institute of Technology, Rochester, NY, USA

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Abstract

It has long been known that high-frequency sensorineural hearing loss (HFHL) can contribute to difficulty in speech understanding by elderly listeners. This study evaluated the relative contribution of HFHL and age to speech understanding. Subjects included adult middle-aged and old groups with normal hearing or with limited HFHL. The Hearing-in-Noise-Test (HINT) was used to measure speech perception performance in quiet and in noise. The middle-aged groups showed significant effects of HFHL for speech intelligibility in quiet and in noise, but the old groups showed the difference in quiet only due to high frequency hearing. The results suggest that HFHL may affect speech intelligibility differently with age and therefore hearing aid selection needs to take into account the influence of age.

Keywords: *Speech Understanding, High Frequency Hearing Loss, Age-related Hearing Loss.*

I. Introduction

The present study investigated the effects of age and high frequency hearing loss on binaural speech perception in quiet and in background noise. Elderly listeners have been shown to suffer greater difficulty with speech understanding than young adult listeners [1] a problem generally attributed to high-frequency sensorineural hearing loss characterized as reduced spectral tuning by the inner-ear. With increased age, it becomes more likely that a decrease in central auditory function (2° CAPD) will follow. In fact, recent studies have suggested that more than the inner ear might be involved. For example, in our previous study [2], we demonstrated an ageeffect on speech understanding in quiet and in noise backgrounds in adult subjects who had audiometric normal hearing, suggesting that age itself contributes to a central auditory processing deficit (1° CAPD). The elderly suffering hearing loss not only had reduced filtering problem, but combined hearing loss-related 2° CAPD and age-related 1° CAPD. The performance of speech understanding in everyday listening conditions has not been fully evaluatedin the elderly because of the difficulty in separating the reduced filtering effect of hearing loss from the effect of aging.

In this study we controlled for differences in hearing loss by matching audiograms of two different age groups. The Hearing-In-Noise-Test (HINT) used in this study to evaluate speech understanding provides several

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Corresponding author: SungHee Kim (sunghee kim@fartima.or.kr)
Daegu Fatima Hospital, 576-31 Shinam 4 Dong, Dong Gu, Daegu 701-600, Korea

advantages over audiologic evaluations that areperformed monaurally under earphones and/or in the quiet condition using tones or words. The HINT not only approximates suprathreshold everyday listening conditions by presenting stimuli in a free field environment but also invokes binaural speech processing. Additionally, the HINT sentence stimuli have somewhat steep performance-intensity functions that enable quantifiably precise thresholds possible [3, 4].

II. Subjects And Methods

2.1. Subjects

Sixty-three subjects were drawn from a pool of 267 adults with hearing data collected at the International Center for Hearing and Speech Research, Rochester, NY, U.S.A., over a five-year period. All were residents of New York State and English was their native language. The subjects were grouped according to age, 18-37 (young), 38-57 (middle-age), and 58 or more years of age (old) and by hearing threshold status. Inorder to evaluate the effect of high frequency hearing, restricted criteria for hearing ranges were applied to produce two different hearing level groups, one with normal hearing and the other with high frequency hearing loss (HFHL). Normal hearing was defined as pure tone hearing thresholds of 25 dB HL or better at 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz. HFHL groups for this study were defined as any symmetrical (less than 21 dB HL difference between two ears) HFHL over 25 dB HL in the frequency range of greater than 2 kHz. Because there were few young adults with HFHL in our data pool, we utilized the following four groups; (1) middle-aged with normal hearing (M, N=16), (2) middle-aged with high frequency hearing loss (HFHL) (MHF, N=9), (3) old group with normal hearing (O, N=19), and (4) old group with HFHL (OHF, N=19). Age and sex distributions are shown in Table 1 and pure tone thresholds of the four groups in Fig. 1.

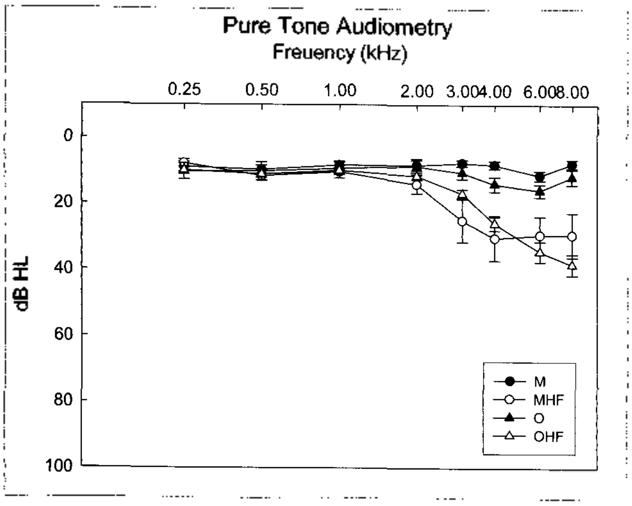

Fig. 1. Audiometric thresholds averaged for the right and left ears of the middle-aged (circles) and old (triangles) groups. Filled circles represent those with normal hearing through high frequency (M and O groups) and unfilled circles for high frequency hearing loss (MHF and OHF groups). Error bars represent standard errors of the mean (S.E.M.).

Table 1. Age and sex distributions of four groups.

Subject Group*	Total Number	No. of Men	No. of Women	Age Ranges (yr-old)
M	16	7	9	39.6 ~ 52.4
MHF	9	4	5	47.5 ~ 55.0
O	19	6	13	61.3 ~ 80.3
OHF	19	6	13	61.0 ~ 78.1

2.2. Methods

The HINT test was administered to subjects seated one meter equidistant from three loudspeakers in a 2.13 m(w) x 2.24 m(l) x 1.98 m(h) double-walled sound booth (Acoustical Systems RE243). Speech was presented at a 0 azimuth in each of the following four conditions: (1) in quiet (HINT Q), (2) in 65 dB (A) of noise located at a 0 azimuth (HINT N0), (3) in 65 dB (A) of noise located at a 90 azimuth (HINT N90), and (4) in 65 dB (A) of noise located at a 270 azimuth (HINT N270).

Sentences and spectrally shaped speech noise from the HINT (Nilsson et al., 1994) compact disc, were digitized with a Tucker-Davis Technologies System II and presented through a Grason- Stadler GSI -16 audiometer. The HINT speech stimuli consisted of 110 sentences (4 lists of 20 sentences and 3 practice lists of 10 sentences). The sentences were of approximately equal length (six to eight syllables) and difficulty (first-grade reading level).

An adaptive procedure [5] without feedback was used to determine the 50% point of the psychometric function required for speech recognition thresholds. During the quiet condition, the beginning intensity level of the speech was 15 dB (A)and the noise channel was turned off. During the noise condition, the beginning intensity level of the speech was 61 dB (A) and the noise channel was turned on and remained at 65 dB (A). The noise onset preceded each sentence by 1 second and was turned off 1 second after each sentence was completed.When the equipment was ready to produce speech and/or noise, the subject could hear the word "GO." Then, a sentence was presented by pressing a button which was under the control of the subject.

The first sentence in each list of sentences was repeated at increasing intensity levels until identified correctly. The intensity level was then decreased by 4 dB and the second sentence was presented. The stimulus level was raised in the case of an incorrect response or lowered in the case of a correct response by 4 dB after the subject's responses to the second and third sentences. The step size was reduced to 2 dB after three sentences, and a simple up-down stepping rule was continued for the remaining 17 sentences. The calculation of the Sentence Speech Reception Threshold (SSRT) necessary for 50 percent sentence recognition was based on averaging the presentation levels of sentences 4 through 10 from the practice list and 4 through 20 from the test list. The practice sentences demonstrated that the subjects could hear and repeat the sentences accurately.

HINT in quiet (HINT Q) thresholds were obtained. In addition,SSRTs of the HINT in noise conditions were employed to establish signal to noise ratio (SNR) thresholds. Young normal hearing adults used to standardize the HINT could meet the 50% correct threshold criterion when the speech was at a decibel level below that of the speech spectrum noise, thus resulting in a negative SNR. Previous studies have shown that a 1 dB SNR improvement is equal to an 11% to 19% improvement in speech intelligibility performance [3, 4, 6].

2.3. Data Analysis

Two-way ANOVAs were done across the variables to show the main effects and interactions between age and high frequency hearing loss and post hoc Bonferroni multiple comparisonswere applied in the four groups to ascertain the inter-group differences using SPSS 11.0.

III. Results

3.1. Validity of Grouping

For the PTA average (average threshold of 0.5, 1, and 2 kHz), the main effects of age and HF and their interaction were not significant. For the HF PTA average (average threshold of 3, 4, 6, and 8 Hz), the main effect of HF [F(1,59)=63,51, $p<0.001$] was significant, but the main effects of age and their interaction were not, using a two-way ANOVA (Table 2).

There were no differences in PTA averages ofthe four different age and hearing loss groups. HF PTA averages in the HF groups (MHF and OHF) were statistically different from those of the normal hearing groups (M and O).

Their interaural threshold differences were calculated as a positive value. The average interaural threshold differences in whole frequency ranges were 3.44 ± 3.79 dB, 5.42 ± 5.22 dB, 4.83 ± 4.93 dB, and 5.14 ± 1.92 dB for group M, MHF, O, and OHF,respectively.

Table 2. The results of two-way ANOVA analysis for the effect of age and high frequency hearing loss on the hearing threshold for frequency ranges of speech spectrum (PTA average) and higher frequency (HF PTA average).

	Source	F	df	p
PTA average	A	0.00	1, 59	0.985
	HF	3.25	1, 59	0.77
	AxHF	0.26	1, 59	0.615
HF PTA average	A	1.83	1, 59	0.181
	HF	63.51	1, 59	⟨0.001***
	AxHF	0.57	1, 59	0.453

3.2. HINT Q; SSRT in Quiet

The results of HINT Q are summarized in Table 3 and Figure 2. The main effect of age and HF were significant [F(1,59)=10.27, $p=0.002$, and F(1,59)=17.90, $p<0.001$, respectively], but their interaction was not (Table 4). Post hoc Bonferroni multiple comparisons showed a significant difference between group M versus group O, MHF and OHF, ($p<0.05$, $p<0.05$and $p<0.001$, respectively) (Table 5).

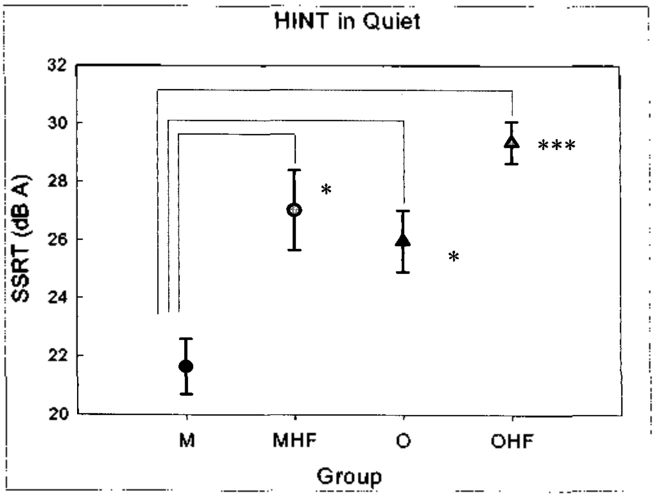

Fig. 2. SSRTs were measured using HINT Q. There were significant main effects of age and high frequency hearing using two-way ANOVA analysis. Error bars represent standard errors of the mean (S.E.M.). * represents p<0.05 and *** p<0.001.

Table 3. HINT results: averages and S.D. of sentence reception threshold (dB A) for HINT Q and SNR (dB) for HINT N0, N90, and N270.

Subject group	HINT Q	HINT N0	HINT N90	HINT N270
M	21.64±3.78	-3.11±1.57	-6.06±1.85	-8.11±1.64
MHF	27.02±4.13	-1.98±1.22	-3.51±1.60	-6.34±1.68
O	25.96±4.62	-1.65±1.00	-4.95±2.40	-6.12±2.30
OHF	29.36±3.13	-1.80±0.86	-4.17±1.55	-5.75±1.74

Table 4. The results of two-way ANOVA analysis for the effect of age (A) and high frequency hearing loss (HFHL) on HINT results.

	Source	F	df	significance
HINT Q	A	10.271	1, 59	p<0.01**
	HFHL	17.90	1, 59	p<0.001***
	AxHFHL	0.91	1, 59	ns
HINT N0	A	7.00	1, 59	p<0.05*
	HFHL	2.53	1, 59	ns
	AxHFHL	4.284	1, 59	p<0.05*
HINT N90	A	0.20	1, 59	ns
	HFHL	10.772	1, 59	p<0.01**
	AxHFHL	3.02	1, 59	ns
HINT N270	A	6.59	1, 59	p<0.05*
	HFHL	4.54	1, 59	p<0.05*
	AxHFHL	1.92	1, 59	ns

3.3. HINT N; Supra-Threshold Processing

The SNR results of HINT N were summarized in Table 3 and Figure 3. The main effect of age was significant for HINT N0 and HINT N270 [F(1,59)=7.00, p=0.01 and F(1,59)=6.59, p=0.013, respectively]. Multiple group comparison showed significant difference between group M and group O at HNT N0 (p<0.01) and HINT N270 (p<0.05). The main effect of HF was significant for HINT N90, and HINT N270 [F(1,59)=10.77, p=0.002 and F(1,59)=4.54, p=0.037, respectively]. However, only HINT N90 showed a significant difference between group M and MHF (p<0.05). HINT N0 showed significant interaction of age and HF [F(1,59)=4.28, p=0.043], but other conditions of HINT N did not..

Table 5. Statistical results of posthoc Bonferroni multiple comparison study.

	2-way ANOVA	Posthoc Bonferroni study		Summary
HINT Q		M vs OHF	p<0.001	M ≠ OHF
	A **	M vs O MHF vs OHF	p<0.05 ns	M ≠ O MHF ≈ OHF
	HFHL ***	M vs MHF O vs OHF	p<0.05 ns	M ≠ MHF O ≈ OHF
HINT N0		M vs OHF	p<0.01	M ≠ OHF
	A *	M vs O MHF vs OHF	p<0.01 ns	M ≠ O MHF ≈ OHF
HINT N90		M vs OHF	p<0.05	M ≠ OHF
	HFHL**	M vs MHF O vs OHF	p<0.05 ns	M ≠ MHF O ≈ OHF
HINT N270		M vs OHF	p<0.01	M ≠ OHF
	A *	M vs O MHF vs OHF	p<0.05 ns	M ≠ O MHF ≈ OHF
	HFHL *	M vs MHF O vs OHF	ns ns	M ≈ MHF O ≈ OHF

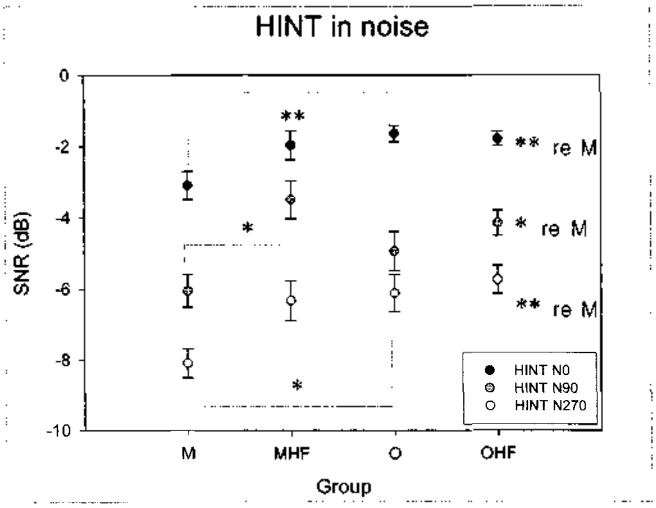

Fig. 3. The SNRs needed for 50% correct speech intelligibility were measured in different noise conditions. Black circles represented for HINT N0, gray circles for HINT N90, and unfilled circles for HINT N270. Error bars represent standard errors of the mean (S.E.M.). * represents p<0.05 and ** p<0.01.

IV. Discussion

Application of the articulation index and the speech transmission index has been introduced to predict the recognition of speech by hearing impaired listeners [7, 8]. Those predictive methods are based on the audiogram, i.e., the loss of sensitivity as a function of frequency [9]. According to these models, the effect of age−related central auditory deficit has not been considered. Because the older adults have poorer hearing sensitivity than younger adults, any age differences in speech understanding could be due solely to peripheral hearing loss. However, one cannot explain how aging influences speech understanding simply by examining age−related differences in auditory sensitivity.

HINT is a measure of speech understanding performance in quiet and noise. The comparison between groups can show the different effects of age and high frequency hearing. For example, the difference between group M (MHF) and O (MHF) is age, which represents the functional deficit of central auditory processing by aging (1° CAPD) (Eq. 1). The difference between group M (O)and MHF (OHF) is the high frequency hearing threshold, which also include 2° CAPD (Eq. 2). The difference between group M and OHF includes not only age−related 1°CAPD, but also high frequency hearing loss and its−related 2° CAPD (Eq. 3).

$$d(\mathrm{M}-\mathrm{O}) = d(\mathrm{MHF}-\mathrm{OHF}) = 1^{\circ}\ \mathrm{CAPD} \cdots\cdots\cdots\cdots (\mathrm{Eq.}\ 1)$$

$$d(\mathrm{M}-\mathrm{MHF}) = d(\mathrm{O}-\mathrm{OHF}) = \mathrm{HFHL} + 2^{\circ}\ \mathrm{CAPD} \cdots (\mathrm{Eq.}2)$$

$$d(\mathrm{M}-\mathrm{OHF}) = d(\mathrm{M}-\mathrm{O}) + d(\mathrm{O}-\mathrm{OHF}) = d(\mathrm{M}-\mathrm{MHF}) + d(\mathrm{MHF}-\mathrm{OHF}) = 1^{\circ}\ \mathrm{CAPD} + \mathrm{HFHL} + 2^{\circ}\ \mathrm{CAPD} \cdots (\mathrm{Eq.}\ 3)$$

Interestingly, the results in the present study showed there were no significant differences between group MHF, O, and OHF. However, there were differences of age and/or high frequency hearing loss in variouslistening conditions. In the quiet condition, there were two main effects of age and high frequency hearing loss, but the difference of HINT Q between group M and OHF was not as large as the simple sum of the differences of the two ($\mathrm{OHF} \approx \mathrm{MHF} \neq \mathrm{M} \neq \mathrm{O} \approx \mathrm{OHF}$). In noise conditions, it seems much more complicated. When the noise was presented with the signal at 0 degree azimuths (HINT N0), there was only a significant age effect. The effect of high frequency hearing loss was concealed ($\mathrm{MHF} \approx \mathrm{M} \neq \mathrm{O} \approx \mathrm{OHF}$). It is not clear whether the high frequency is not so important for such a condition, or that the elderly can compensate for this problem by top−down processing mechanisms. When noise was separated from the signal, speech understanding was improved in all groups. When noise was coming from the right side (HINT N90), there was only significant effect of high frequency hearing loss ($\mathrm{OHF} \approx \mathrm{MHF} \neq \mathrm{M} \approx \mathrm{O}$). However, when the noise was coming from the left side (HINT N270), age and high frequency hearing were significantly important, but there was not a significant group difference between group M and MHF ($\mathrm{MHF} \approx \mathrm{M} \neq \mathrm{O} \approx \mathrm{OHF}$). It might be that compensatory mechanisms regarding speech understanding in quiet and noise differ. Once we have gained a better understanding of how changes in the central auditory system contribute to difficulties in speech understanding, we should be able to develop methods for helping elderly people overcome and compensate for such deficits.

V. Summary

There were significant effects of aging and high frequency hearing on binaural speech understanding in quiet and in noise. However, the effect of high frequency hearing appeared significant only in the middle−aged groups, especially for HINT Q and HINT N90. There was a significant difference by age group in the normal hearing group, but not in the high frequency hearing loss groups, especially for HINT Q, HINT N0 and HINT N270.

These results suggest that sensory distortions characteristic of high frequency hearing loss contribute to speech−understanding difficulties for the middle−aged. The elderly may suffer not only sensory distortions from high frequency hearing loss, but also a central auditory processing deficit. On the other hand, the complicated compensations for speech understanding in the elderly obscure the effects of hearing loss and age. Consequently, in rehabilitation, the elderly might not benefit as much as younger adults even using multiband amplification to compensate for the reduced filtering characteristics of the inner ear. Therefore, specific compensatory strategies for the elderly might be needed for improving speech understanding in everyday listening situations that present competing noise sources, reverberation, fast or unclear speakers, and the limited bandwidths characteristic of telephones.

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[Profile]

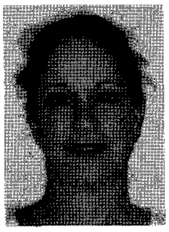
- **SungHee Kim**

SungHee Kim received the medical license (M.D.) and Korean Board of Otolaryngology after graduation of Kyungpook National University, Daegu, Korea, in 1991 and 1996 respectively, and B.S. and Ph.D. degree in Otolaryngology from the same University in 1994 and 2006 respectively. Since 2003, she worked for Daegu Fatima Hospital, as a chief of otolaryngology department. Her research interests include auditory physiology of the auditory efferent system with age, otoacoustic emissions, and effect of age and sensorineural hearing loss on speech intelligibility in background noise.

- **Robert D. Frisina**

Robert D. Frisina received his Ph.D. in Bioengineering and Neuroscience from Syracuse University. He did Post-Doctorial research at the University of Rochester Medical School in Sensory Biophysics of the auditory system. He is currently Assoc. Chair of Otolarygology, and Professor of Otolaryngology, Biomedical Engineering, Neurobiology & Anatomy and Communication Sciences and Disorders at the University of Rochester Medical School, Rochester NY, USA. In addition he is Assoc. Director of the International Center for Hearing & Speech Research and Distinguished Researcher in Biological Sciences at the Rochester Institute of Technology. He now studies age-related changes in the auditory system, and potential therapeutic interventions for treating hearing impairment, deafness and age-related hearing loss-presbycusis, using both clinical populations and animal models.

- **Susan T. Frisina**



Susan T. Frisina, R.N. received her nursing degree from St. Joseph' s School of Nursing in 1983. She has worked in geriatrics, women' s health and pre/postoperative units for 25 years. She currently works at the International Center for Hearing and Speech Research as Research Coordinator.

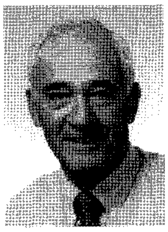
- **Frances M. Mapes**

Frances M. Mapes received B.A. in Speech Pathology and Audiology from Balor University in 1973, and an M.A. in Audiology from Northwestern University in 1975. She has been an audiologist at the International Center for Speech anc Hearing Research at RIT from 1998 to the present.

- **Elizabeth D. Hickman**

Elizabeth D. Hickman received an A.B. degree in botany from the University of North Carolina, Chapel Hill, N.C., in 1970 and a B.S. degree in genetics from North Carolina State University, Raleigh, N.C., in 1972. Since 1996 she has worked at a computer programmer at the International Center for Hearing and Speech Research, National Technical Institute for the Deaf, Rochester Institute of Technology, Rochester, NY.

- **D. Robert Frisina**



D. Robert Frisina received his Ph.D. from Northwestern University. He is a Professor of Communication Sciences and Director of the International Center for Hearing & Speech Research at the National Technical Institute for the Deaf at Rochester Institute of Technology, Rochster, NY. Dr. Frisina was the founding director of the National Technical Institute for the Deaf. He currently leads a team of scientists from Rochester Institute of Technology and the University of Rochester Medical Center in an NIH-NIA sponsored study to characterize and determine the neural and molecular bases of presbycusis (age-related hearing loss).