

Age- and gender-specific reference ranges for hearing level and longitudinal changes in hearing level

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This paper presents age-specific reference ranges for hearing level and change in hearing level for men and women at 500, 1000, 2000, and 4000 Hz. The percentiles are constructed from data obtained from persons in the Baltimore Longitudinal Study of Aging who were rigorously screened for otological disorders and evidence of noise-induced hearing loss. The resulting percentile curves represent norms for changes in hearing level in the absence of any known otologic disease. These percentile curves provide a reference for detecting when a person deviates from a normal pattern of change, thus helping in diagnosing problems with hearing or in monitoring hearing in occupational settings. The smoothed means and standard deviations of the hearing levels were used to construct the longitudinal percentiles. The percentiles for cross-sectional change were constructed using the skew normal distribution to allow for the percentiles to be asymmetric on either side of the median level. These percentiles are the first reference curves that (1) provide standards for hearing level changes over periods of up to 15 years, (2) account for age differences in the distribution of hearing levels, and (3) are based on data from persons who have been systematically screened for otological disorders and evidence of noise-induced hearing loss. © 1996 Acoustical Society of America.

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INTRODUCTION

Recently, we presented a report of estimated longitudinal changes in hearing thresholds in a large sample of men and women from the Baltimore Longitudinal Study of Aging (BLSA) who were rigorously screened for hearing disorders and evidence of noise-induced hearing loss (Pearson *et al.*, 1995). The data showed three principal findings: (1) at most ages and frequencies, the rate of longitudinal change in hearing level over a 10-year period is more than twice as fast in men than in women although both men and women are at risk for age-related hearing loss; (2) men have better hearing thresholds than women at frequencies below 1000 Hz beginning at age 30 years, whereas women have better hearing thresholds than men above 1000 Hz at all ages, and this gender reversal is not attributable to differential noise-induced hearing loss in women and men; and (3) there is a significant degree of between-subject variability in the longitudinal pattern of change in hearing thresholds which increases with age.

One application of the longitudinal hearing threshold data is to serve as reference values for determining whether or not an individual's change in hearing threshold corresponds to the expected age-related decline in threshold. If an individual's threshold decline exceeds the expected age-related threshold shift, then this finding would indicate the development of abnormal hearing loss. However, in order to make this determination, percentile curves of the longitudinal

change in hearing threshold need to be constructed that are age, gender, and frequency specific. In this paper, we extend the findings of the earlier Pearson *et al.* (1995) report to construct percentiles of cross-sectional hearing level as well as longitudinal change in hearing level for both men and women. Although the ISO/7029-1984 (ISO, 1984) standard provides median curves for hearing level for ages 18–70 years as well as the standard deviations, the data used to develop this standard represents a meta-analysis of cross-sectional studies which did not uniformly perform otological examinations or screen rigorously for noise exposure among the participants. Other reports similarly have presented cross-sectional age-related changes in hearing threshold from unscreened or minimally screened populations [e.g., Vital and Health Statistics—Series 11 (1980)], or populations within a limited age range (Harford and Dodds, 1982). To establish references for normal change in hearing, percentile curves of longitudinal changes in hearing at each frequency need to be developed based on data collected from a large sample of men and women who are screened rigorously for otologic disorders and noise exposure. The present report serves this purpose. In addition, percentiles constructed for the average of 2000, 3000, and 4000 Hz are presented to facilitate determination of the proportion of screened subjects exhibiting a standard threshold shift (STS). A STS is “a change in hearing threshold relative to the baseline audiogram of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either

TABLE I. Median number of men in the time intervals for assessing longitudinal change for 0.5, 1, 2, and 4 kHz.

Time interval	Starting age interval					
	30–39.9	40–49.9	50–59.9	60–69.9	70–79.9	80–89.9
1–2.9	64	48	46	51	71.5	51.5
2–3.9	65.5	59	55	63	81	52
3–4.9	50.5	53.5	65.5	74.5	72	38.5
4–5.9	48	43.5	62.5	64.5	69	31.5
5–6.9	40	30	63.5	56.5	64.5	17.5
6–7.9	44	32	62.5	55	61	14.5
7–8.9	39.5	27.5	49.5	48	53.5	...
8–9.9	37	24	46.5	45	36.5	...
9–10.9	24	29	46	39.5	23.5	...
10–11.9	33	27	44.5	38.5	22.5	...
11–12.9	30	25	35.5	33	17.5	...
12–13.9	21.5	21.5	40.5	32.5	...	...
13–14.9	19.5	19	42	34.5	...	...
14–15.9	17	23.5	32.5	32	...	...

ear’’ (OSHA, 1983) and is used to indicate the onset of noise-induced hearing loss.

I. METHOD

A. Population, apparatus, and procedures

The study population, instrumentation, and procedures are identical to those reported previously (Pearson *et al.*, 1995). Briefly, the study group consists of 681 Caucasian men and 416 Caucasian women who participate in the BLSA (Shock *et al.*, 1984), whose beginning age in the study is between 17 and 90 years and who entered the study between 1966 and 1991. Participants are tested biannually. Each of the participants passed a rigorous screening procedure for evidence of otologic disease, unilateral hearing loss, or noise-induced hearing loss at each visit.

The hearing thresholds are determined from a Bekesy audiogram obtained using a swept (100–10 000 Hz), pulsed pure tone (200 ms on/200 ms off, 25-ms rise/fall time) generated by a Grason-Stadler 1701 audiometer. Subjects track their own thresholds using a push-button response. Threshold levels are determined from the audiogram at 1-dB steps at each frequency by linear interpolation between the mid-points of the tracking excursions. All thresholds are expressed in dB HL using the ANSI (1989) standards. The Bekesy self-tracking procedure is used extensively in industrial settings (Morrill, 1986); thus the results obtained in the present study should agree well with those obtained with the use of similar procedures. Moreover, the derivation of threshold to the nearest 1-dB step is expected to be consistent with threshold derivations made to the nearest 5-dB step in which test–retest reliability is within ± 5 dB.

The percentiles presented in this paper are calculated at 500, 1000, 2000, and 4000 Hz, which represent the frequency range comprising most critical energy in speech. The cross-sectional percentiles are computed from the data at the last visit for each participant. The longitudinal changes are computed as changes in hearing level from the second visit to each subsequent visit. Participants in the original screened data set with fewer than three visits are excluded from this

TABLE II. Median number of women in the time intervals for assessing longitudinal change for 0.5, 1, 2, and 4 kHz.

Time interval	Starting age interval					
	30–39.9	40–49.9	50–59.9	60–69.9	70–79.9	80–89.9
1–2.9	24	37.5	27.5	29.5	31	22
2–3.9	23.5	33.5	29	27	33	17
3–4.9	19	25.5	25	31.5	26	...
4–5.9	18	27	23	29.5	18	...
5–6.9	14.5	21	20	21	...	...
6–7.9	14	23	21	20	...	...
7–8.9	...	15	15	13.5	...	...
8–9.9	...	...	...	13.5	...	...

portion of the study. With these exclusions, the data reported on longitudinal change are hearing thresholds of 456 men and 234 women at varying time intervals.

B. Statistical methods

1. Longitudinal change in hearing level

Pearson *et al.* (1995) found that there is a small learning effect on the order of a 0.1- to 1.9-dB improvement in thresholds from the first to subsequent visits in both men and women. To assess the longitudinal changes in hearing level, for each participant we computed the change in hearing level and time change from the second visit to each subsequent visit. Use of the thresholds obtained at the second visit to represent baseline data eliminates the learning effect. For each of six age decades (30 to 39.9, 40 to 49.9, 50 to 59.9, 60 to 69.9, 70 to 79.9, and 80 to 89.9) we computed the mean and standard deviations of these changes in hearing levels in overlapping two-year time intervals (1 to 2.9, 2 to 3.9, up to 14 to 15.9). Because the means and standard deviations are quite variable from interval to interval, a cubic *B*-spline (Statistical Sciences, Inc., 1993) is used to obtain smooth percentiles. Each time interval for the longitudinal percentiles was required to contain at least 15 observations.

The p th percentile for change in hearing level is then computed as

$$\text{smoothed mean} + z_p \times \text{smoothed standard deviation}, \quad (1)$$

where z_p is the p th percentile for the standard normal distribution.

The Occupational Safety and Health Act (OSHA, 1983) defines an STS as “a change in hearing threshold relative to the baseline audiogram of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either ear.” The percentiles for the STS are computed in the same fashion using the mean threshold at 2, 3, and 4 kHz.

2. Cross-sectional hearing level

To assess cross-sectional differences in hearing level we used the participants’ hearing levels at their last visit. While it is reasonable to assume that changes in hearing levels follow the symmetric normal distribution, it is not a plausible assumption that the actual hearing levels are symmetric at all ages. To allow for the cross-sectional hearing levels to be skewed, we employ the skew normal distribution to model

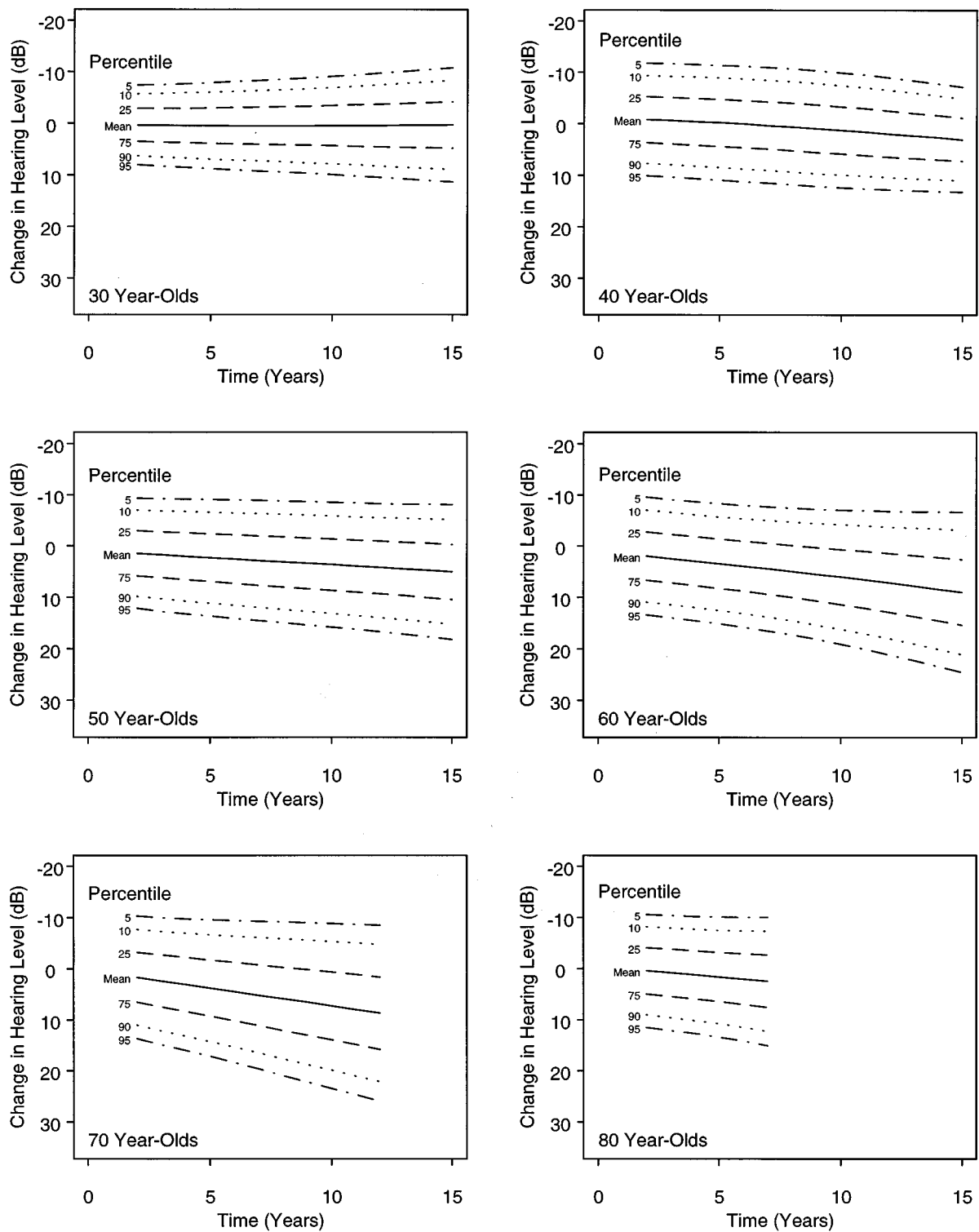


FIG. 1. Percentiles of longitudinal change in hearing level in men at 0.5 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s. A positive change in hearing level indicates a loss in hearing level while a negative change indicates an improvement in hearing.

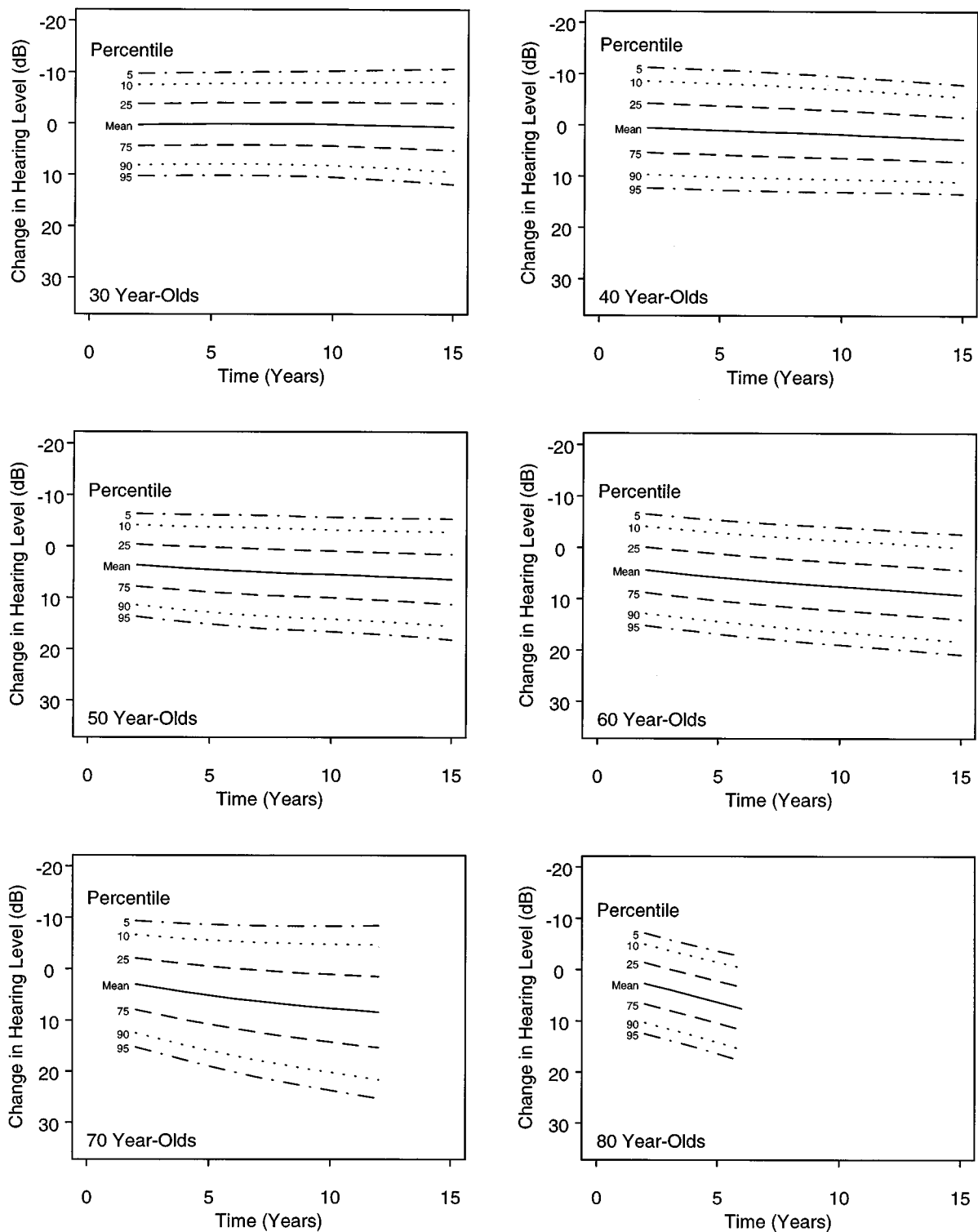


FIG. 2. Percentiles of longitudinal change in hearing level in men at 1 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

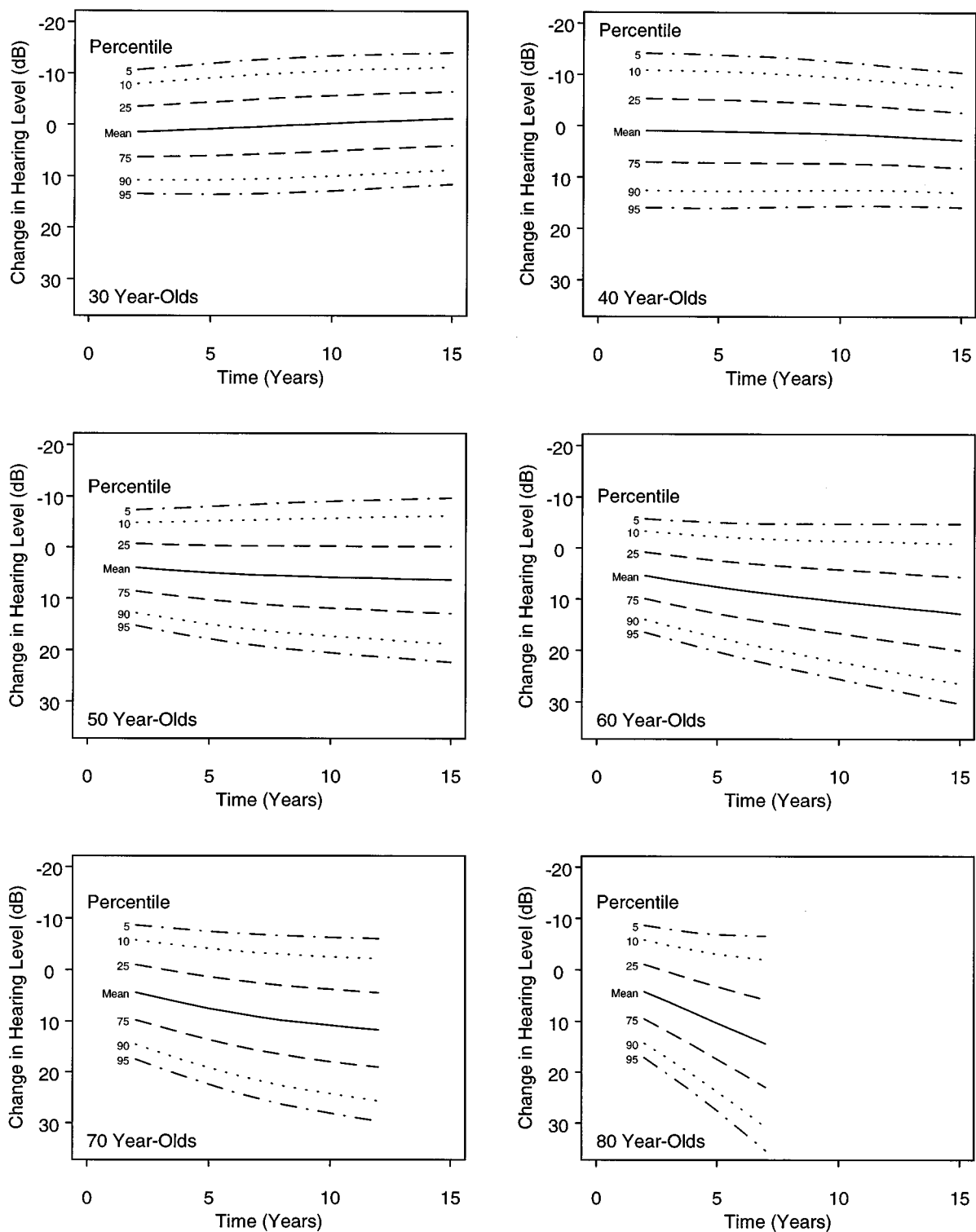


FIG. 3. Percentiles of longitudinal change in hearing level in men at 2 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

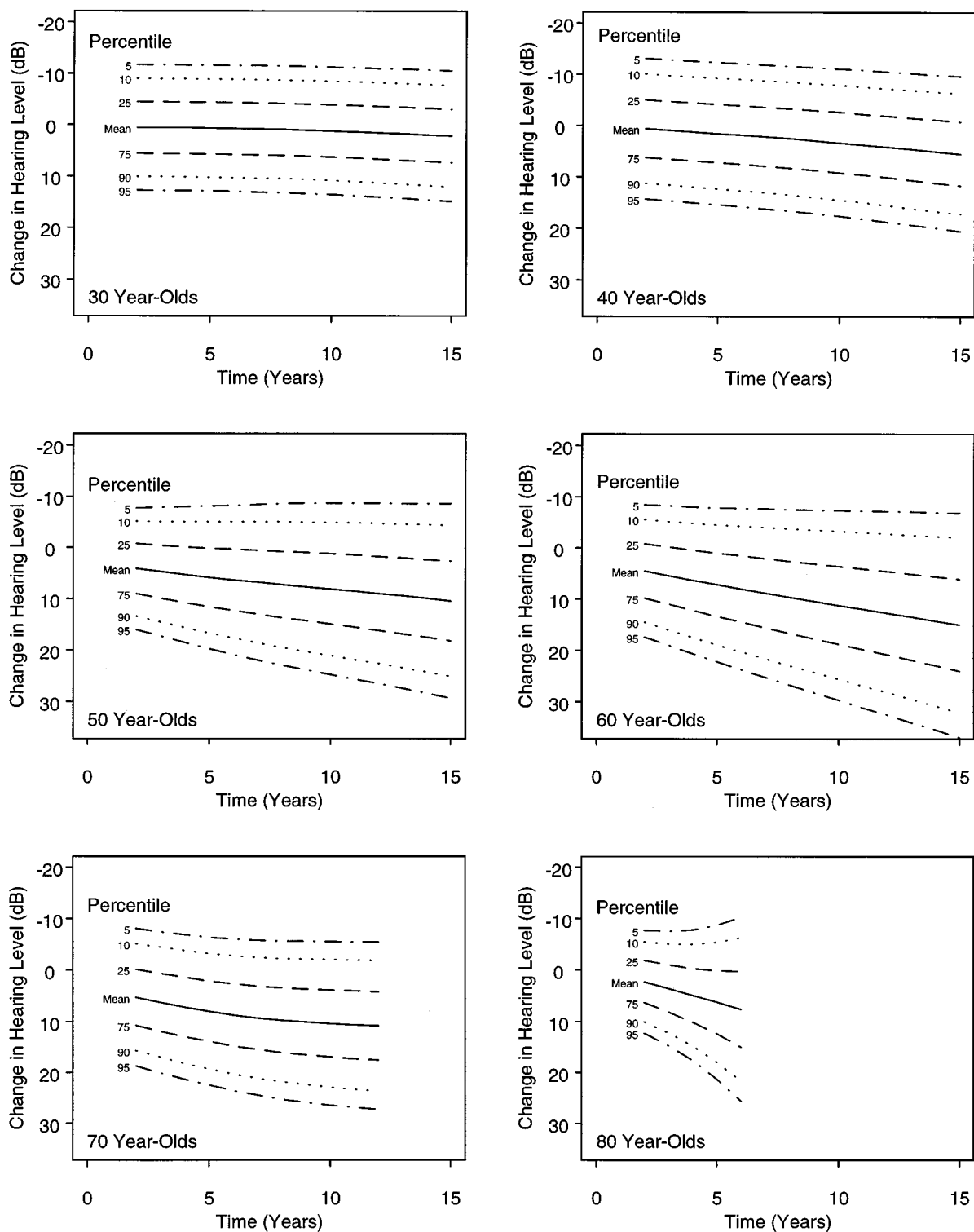


FIG. 4. Percentiles of longitudinal change in hearing level in men at 4 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

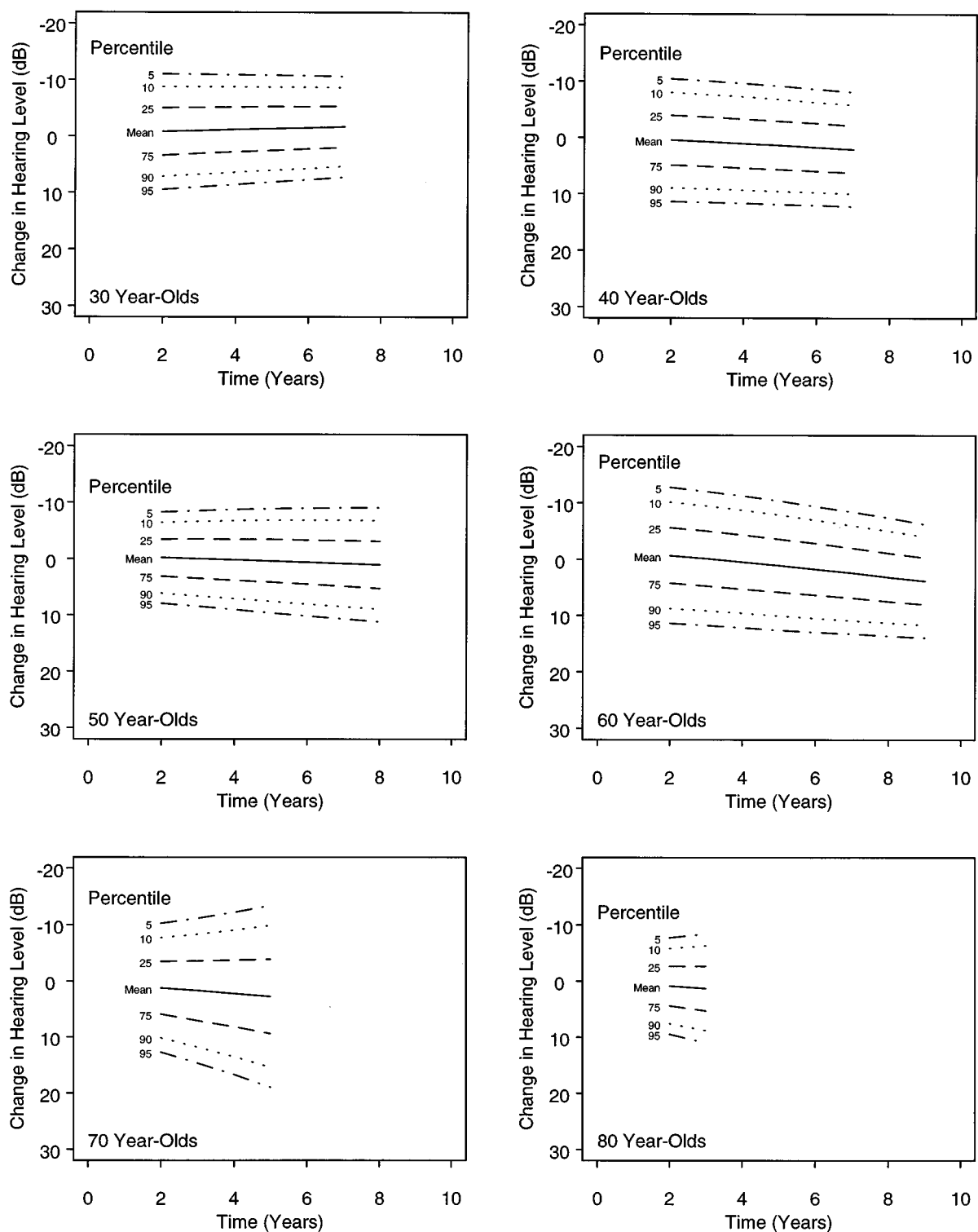


FIG. 5. Percentiles of longitudinal change in hearing level in women at 0.5 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

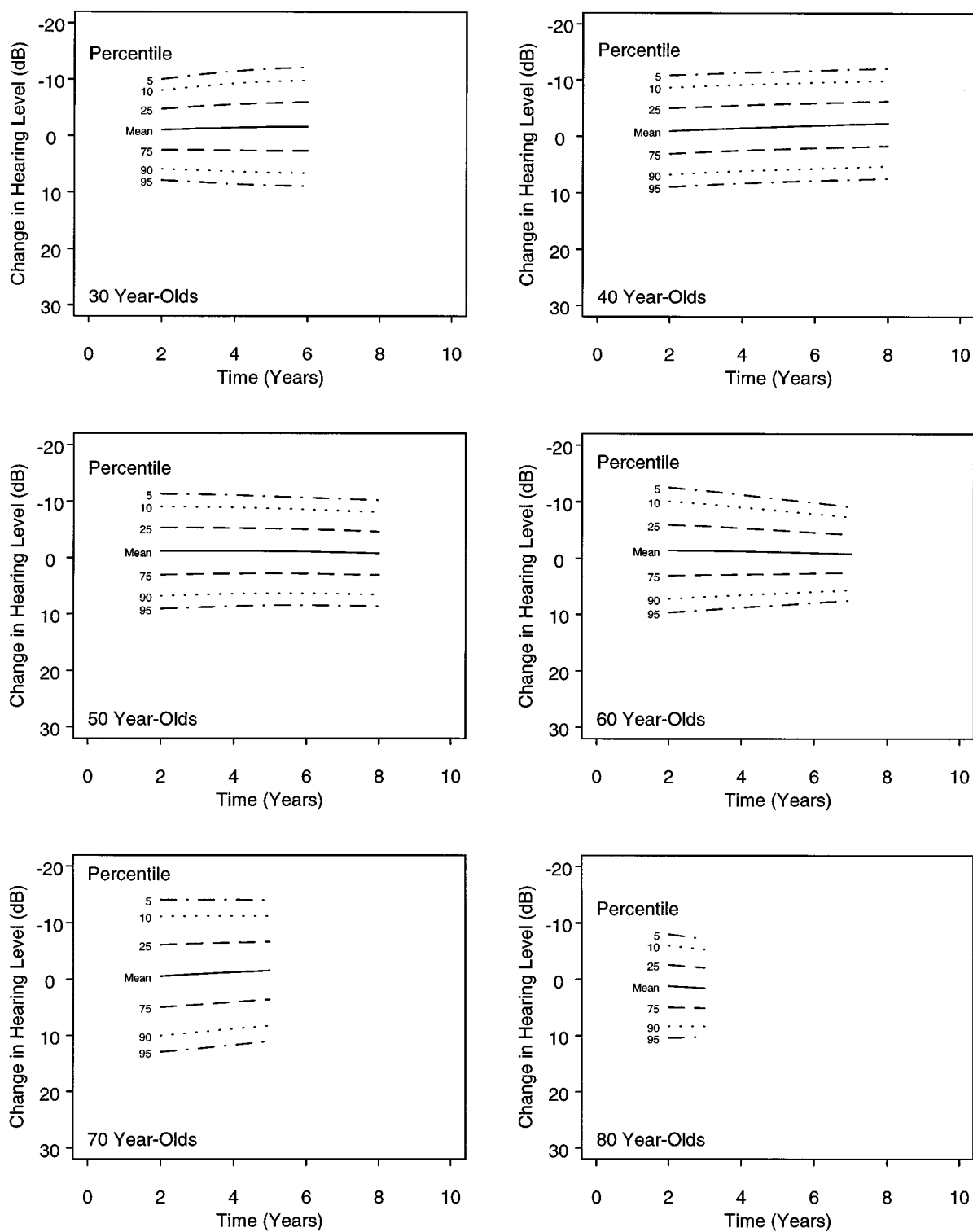


FIG. 6. Percentiles of longitudinal change in hearing level in women at 1 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

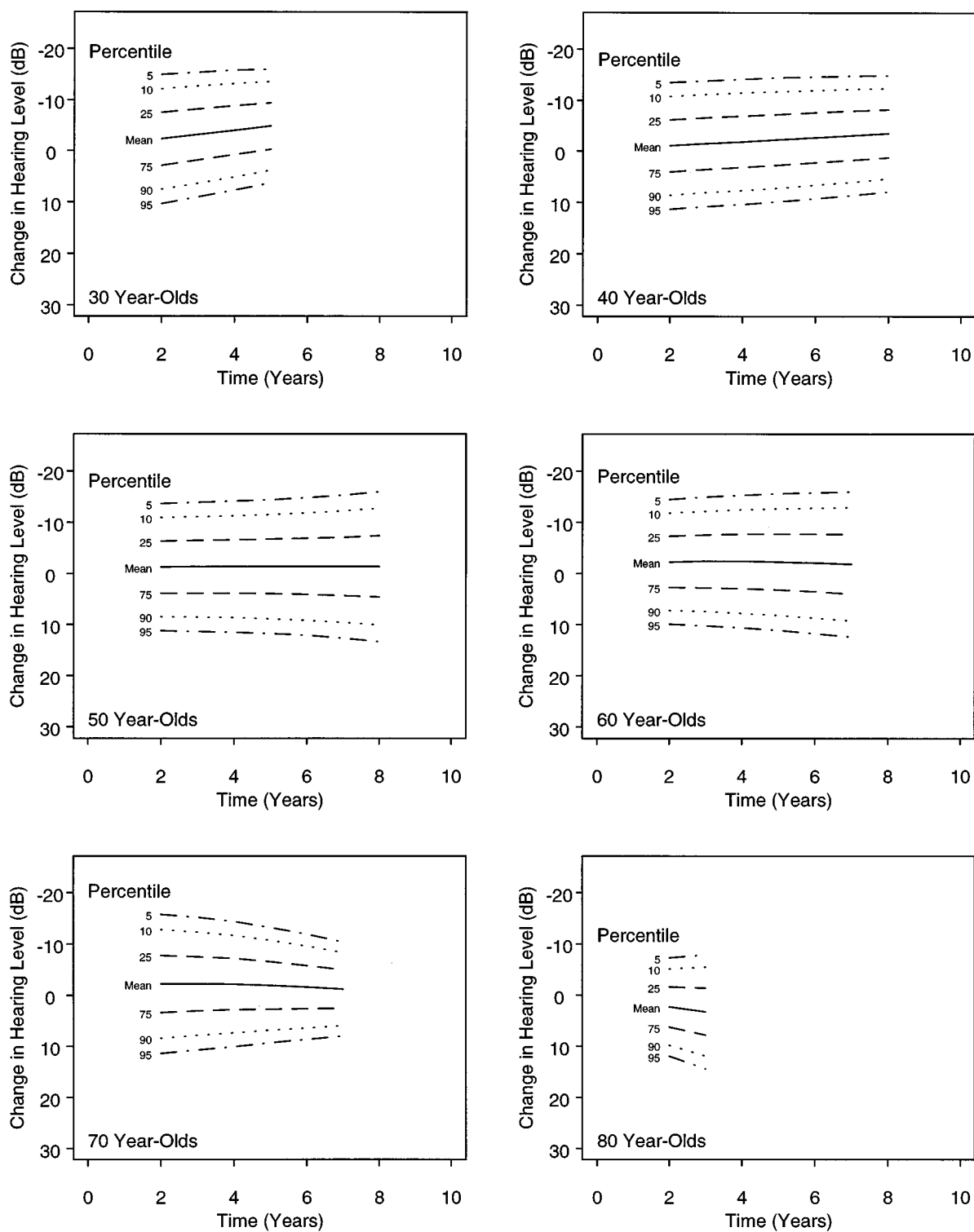


FIG. 7. Percentiles of longitudinal change in hearing level in women at 2 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

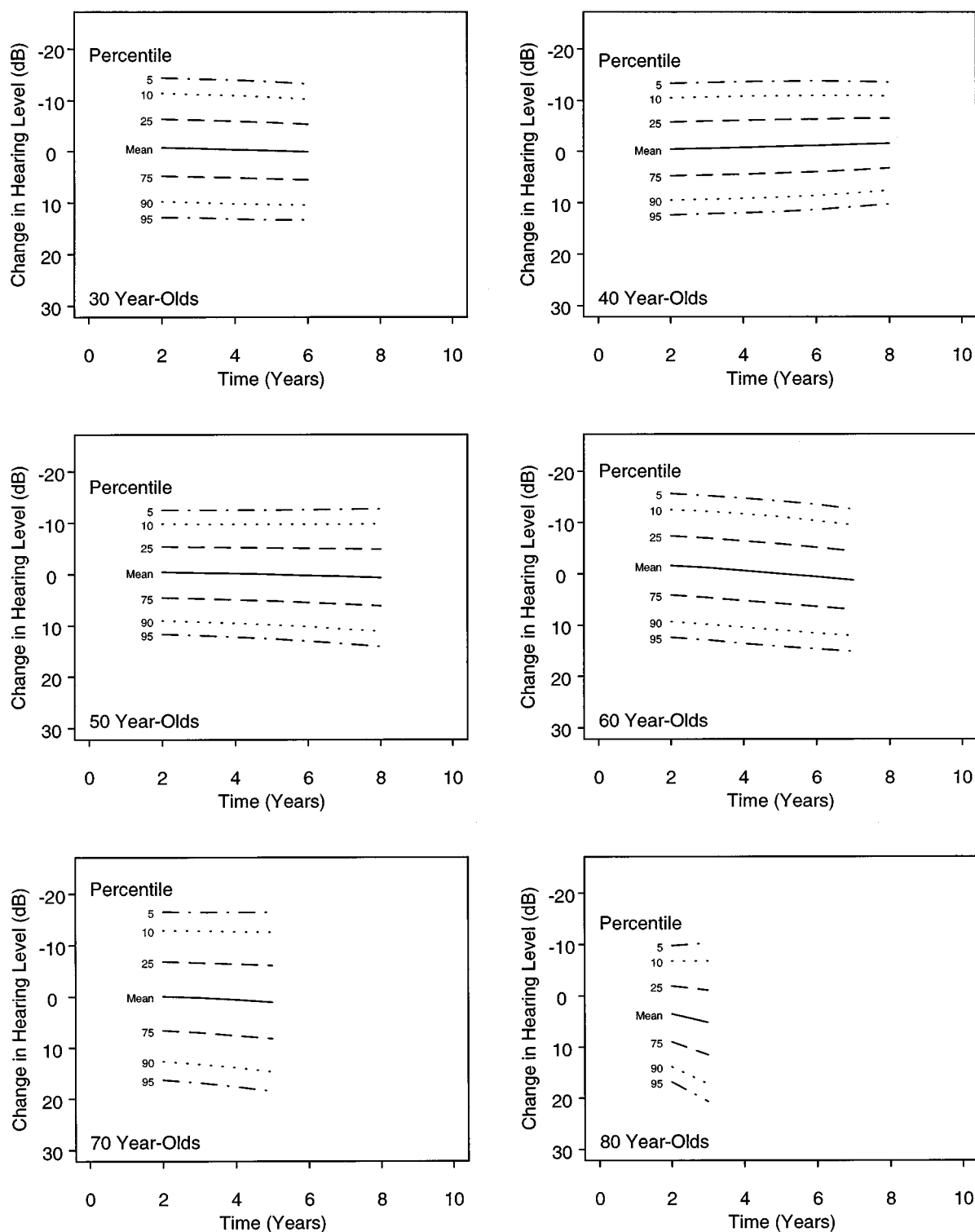


FIG. 8. Percentiles of longitudinal change in hearing level in women at 4 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

TABLE III. Smoothed means and smoothed standard deviations for longitudinal change in hearing level in men (mean, standard deviation).

Starting age	Frequency	Follow-up time						
		2	4	6	8	10	12	14
30	0.5	0.3, 4.7	0.4, 4.9	0.5, 5.2	0.5, 5.5	0.4, 5.8	0.4, 6.2	0.3, 6.5
	1	0.2, 6.1	0.1, 6.1	0.1, 6.1	0.1, 6.2	0.1, 6.3	0.3, 6.5	0.5, 6.7
	2	1.4, 7.3	1.0, 7.6	0.6, 7.8	0.2, 8.0	-0.3, 8.0	-0.7, 7.9	-1.0, 7.8
	4	0.5, 7.4	0.6, 7.4	0.7, 7.5	0.9, 7.5	1.2, 7.5	1.6, 7.6	2.0, 7.7
	Ave. 2, 3, 4	0.5, 6.4	0.5, 6.6	0.5, 6.7	0.5, 6.8	0.5, 6.8	0.6, 6.7	0.8, 6.6
40	0.5	-0.8, 6.7	-0.4, 6.7	0.0, 6.8	0.6, 6.8	1.2, 6.8	1.9, 6.6	2.7, 6.4
	1	0.5, 7.2	0.8, 7.1	1.1, 7.1	1.4, 7.0	1.8, 6.9	2.1, 6.7	2.5, 6.6
	2	0.9, 9.2	1.0, 9.1	1.1, 9.0	1.3, 8.8	1.5, 8.6	1.9, 8.3	2.4, 8.1
	4	0.6, 8.3	1.2, 8.4	1.8, 8.5	2.5, 8.6	3.3, 8.7	4.1, 8.9	5.0, 9.1
	Ave. 2, 3, 4	0.4, 7.7	0.9, 7.7	1.5, 7.8	2.0, 7.8	2.7, 7.8	3.5, 7.8	4.3, 7.8
50	0.5	1.4, 6.5	2.0, 6.8	2.6, 7.0	3.1, 7.2	3.6, 7.4	4.2, 7.6	4.8, 7.8
	1	3.6, 6.1	4.3, 6.3	4.8, 6.6	5.1, 6.7	5.5, 6.8	5.8, 6.9	6.2, 7.0
	2	4.0, 6.9	4.7, 7.5	5.2, 8.1	5.6, 8.6	5.8, 9.0	6.0, 9.3	6.2, 9.6
	4	4.1, 7.2	5.3, 8.1	6.3, 8.9	7.2, 9.6	8.1, 10.2	9.0, 10.7	9.9, 11.2
	Ave. 2, 3, 4	3.5, 5.6	4.6, 6.2	5.6, 6.7	6.6, 7.1	7.4, 7.5	8.3, 7.7	9.2, 8.0
60	0.5	1.9, 7.0	2.9, 7.1	3.9, 7.2	4.9, 7.5	6.0, 7.9	7.2, 8.5	8.4, 9.1
	1	4.3, 6.6	5.3, 6.7	6.2, 6.8	6.9, 6.9	7.5, 6.9	8.2, 7.0	8.8, 7.1
	2	5.4, 6.7	6.9, 7.4	8.3, 8.0	9.4, 8.6	10.4, 9.2	11.4, 9.8	12.3, 10.4
	4	4.5, 7.9	6.3, 8.7	8.0, 9.6	9.6, 10.4	11.2, 11.3	12.7, 12.1	14.3, 12.9
	Ave. 2, 3, 4	4.6, 6.8	6.4, 7.2	8.1, 7.6	9.6, 7.9	11.1, 8.3	12.7, 8.6	14.2, 9.0
70	0.5	1.7, 7.3	3.1, 7.8	4.5, 8.4	5.9, 9.1	7.3, 9.8	8.7, 10.5	
	1	3.0, 7.5	4.5, 8.1	5.8, 8.7	6.8, 9.2	7.7, 9.7	8.5, 10.2	
	2	4.4, 7.9	6.5, 8.7	8.4, 9.4	9.8, 10.0	10.9, 10.5	11.8, 10.8	
	4	5.3, 8.2	7.2, 8.6	8.8, 9.0	9.8, 9.4	10.4, 9.7	10.9, 9.9	
	Ave. 2, 3, 4	4.7, 7.0	6.5, 7.3	8.1, 7.7	9.5, 8.0	10.6, 8.2	11.7, 8.2	
80	0.5	0.5, 6.7	1.3, 7.0	2.1, 7.4				
	1	2.7, 6.0	5.2, 6.0	7.6, 6.2				
	2	4.2, 7.9	8.3, 9.5	12.4, 11.6				
	4	2.3, 6.1	5.0, 7.7	7.7, 10.9				
	Ave. 2, 3, 4	3.0, 5.6	6.6, 7.7	10.4, 10.3				

the hearing levels in overlapping 5-year age intervals (20 to 24.9, 22.5 to 27.4, up to 87.5 to 92.4) (Schork and Schork, 1988; Pearson *et al.*, 1992). If x represents the untransformed, skew data, then

$$y = (x^\lambda - 1)/\lambda + \lambda, \quad \text{if } \lambda \neq 0, \quad \text{and} \quad y = \ln(x) \quad \text{if } \lambda = 0. \quad (2)$$

The transformed variable is represented by y and λ is the skewness parameter. The skew normal assumes that this transformed variable y follows a normal distribution and the skewness parameter λ must be estimated. This is achieved using maximum likelihood (Schork and Schork, 1988; Pearson *et al.*, 1992). The skew normal requires that all the data be positive. To accomplish this, we added 25 to each of the hearing level values.

The skewness parameter, mean, and standard deviation of the transformed data, y , are estimated for each of the age intervals. Then the percentiles of the transformed data are computed as

$$\text{mean of } y + z_p \times \text{standard deviation of } y. \quad (3)$$

The percentiles of the hearing levels are calculated by reversing the procedure in (2) and subtracting 25. Finally, these percentiles are smoothed using cubic B -splines. Each age

interval was required to contain at least 15 observations for the cross-sectional percentiles.

II. RESULTS

A. Longitudinal change in hearing level

Tables I and II present the median sample sizes in the overlapping time intervals for the men and women. There are very minor fluctuations among the sample sizes at each age and length of follow-up interval. In each age-time group the only differences in sample size among the frequencies is due to missing hearing levels at particular frequencies for the participants. Figures 1–4 present the percentiles for changes in hearing level for men at 500, 1000, 2000, and 4000 Hz, respectively, while Figs. 5–8 provide the corresponding percentiles for women. Tables III and IV present the corresponding smoothed means and smoothed standard deviations for men and women, respectively. Equation (1) may be used to compute percentiles based on these means and standard deviations.

In men there was little change in mean hearing level over 15 years in the young age groups (30 and 40 year olds) at all frequencies. Further, the percentiles have fairly constant deviation from the mean at these young ages. As the

TABLE IV. Smoothed means and smoothed standard deviations for longitudinal change in hearing level in women (mean, standard deviation).

Starting age	Frequency	Follow-up time			
		2	4	6	8
30	0.5	-0.8, 6.2	-1.2, 5.9	-1.5, 5.6	
	1	-1.1, 5.4	-1.5, 6.1	-1.6, 6.4	
	2	-2.3, 7.7	-4.0, 7.1		
	4	-0.8, 8.2	-0.4, 8.2	0.1, 8.0	
	Ave. 2, 3, 4	-1.7, 6.6	-2.4, 6.8	-3.0, 7.4	
40	0.5	0.4, 6.6	1.0, 6.5	1.7, 6.3	
	1	-1.0, 6.0	-1.5, 6.0	-2.0, 6.0	-2.3, 5.9
	2	-1.1, 7.5	-1.9, 7.4	-2.7, 7.2	-3.5, 6.9
	4	-0.5, 7.8	-0.8, 7.8	-1.2, 7.7	-1.6, 7.2
	Ave. 2, 3, 4	-0.9, 6.6	-1.5, 6.3	-2.2, 5.9	-2.8, 5.3
50	0.5	-0.2, 4.9	0.2, 5.4	0.6, 5.8	1.1, 6.2
	1	-1.1, 6.2	-1.2, 6.0	-1.1, 5.8	-0.8, 5.7
	2	-1.2, 7.6	-1.3, 7.8	-1.3, 8.2	-1.3, 8.9
	4	-0.4, 7.4	-0.1, 7.5	0.2, 7.8	0.7, 8.2
	Ave. 2, 3, 4	-0.6, 6.7	-0.4, 6.6	-0.0, 6.6	0.4, 7.0
60	0.5	-0.7, 7.3	0.5, 7.1	1.8, 6.8	3.2, 6.4
	1	-1.4, 6.7	-1.2, 6.1	-0.9, 5.4	
	2	-2.2, 7.4	-2.4, 7.9	-2.0, 8.4	
	4	-1.6, 8.5	-0.6, 8.6	0.6, 8.5	
	Ave. 2, 3, 4	-1.7, 7.9	-1.2, 7.3	-0.4, 6.7	
70	0.5	1.3, 7.0	2.3, 8.8		
	1	-0.6, 8.2	-1.2, 7.8		
	2	-2.2, 8.3	-2.2, 7.4	-1.6, 6.3	
	4	-0.1, 10.0	0.6, 10.4		
	Ave. 2, 3, 4	-1.0, 8.1	-1.1, 8.1		
80	0.5	0.9, 5.2			
	1	1.2, 5.6			
	2	2.3, 5.8			
	4	3.5, 8.1			
	Ave. 2, 3, 4	3.0, 5.3			

age decade increases, the change in hearing level increases with time. At 4 kHz, in 50- and 60-year-olds, the spread of the percentiles increases with follow-up time. In 80-year-old men at 4 kHz, the percentiles show a dramatic increase in spread in the percentiles with increasing time.

Due to the smaller number of women and their length of follow-up, the longitudinal changes are only evaluated for up to a maximum of 9 years of follow-up. At 1, 2, and 4 kHz, young women show a slight improvement in their hearing thresholds. Thereafter they have a moderate increase in hearing level with time.

Figures 9 and 10 present the percentiles and Tables III and IV give the smoothed means and standard deviations of the STS for men and women, respectively. The graphs for the men have similar shapes to the graphs at 4 kHz (Fig. 4) while the graphs for the women are more similar to their 2-kHz graphs (Fig. 7).

B. Cross-sectional hearing level

Table V presents the median sample sizes in the overlapping age intervals for the men and women. Again there are very minor fluctuations among the sample sizes at each age interval. Figures 11 and 12 present the cross-sectional

percentiles for the men and women, respectively, at the four frequencies. Tables VI and VII present the cross-sectional medians.

In the 20 s there is a small amount of spread in the hearing level of men at all four frequencies. The hearing level deteriorates fairly constantly with age and the percentiles become more spread out with age as well. At 0.5, 1, and 2 kHz at the older ages the percentiles exhibit significant skewness, while at 4 kHz there is skewness in the young and middle ages but the percentiles are more symmetric in the oldest age groups.

In women deterioration in hearing level accelerates with age at all four frequencies. In addition, there is skewness in the old ages at 0.5, 1, and 2 kHz, but at 4 kHz the percentiles are more symmetric (as with the men).

Figure 13 and Tables VI and VII present the cross-sectional changes in the average hearing level at 2, 3, and 4 kHz for the men and women. At young ages less than 5% of the men and women have hearing levels greater than 10 dB. The proportion increases with age. By about age 40, 50% of the men have hearing levels greater than 10 dB and at 90 years of age about 95% have hearing levels greater than 10 dB. In women, at about 60 years of age 50% have hearing levels exceeding 10 dB, and at 85 years of age about 90% have hearing levels over 10 dB.

III. DISCUSSION

A. Longitudinal change in hearing level

In 30-year-old men, there is little change in mean hearing level. At 0.5 kHz the percentiles show increase in spread with time but at 1 and 4 kHz the percentiles are almost parallel to the mean curves. Men in the 40-, 50-, 60-, and 70-year-old groups show a small decline in hearing level over 15 years of follow-up at all frequencies. At 0.5 kHz the percentiles spread out for 60-year-olds, at 1 kHz the percentiles spread out for 70-year-old men, at 2 kHz the percentiles spread out slightly in the 50, 60, and 70 age groups and more in the 80-year-old group, and at 4 kHz the percentiles spread out for both 50- and 60-year-olds. Among the oldest men, there is a sharp decline in hearing level at 1, 2, and 4 kHz with the percentiles rapidly spreading out at 2 and 4 kHz. At 0.5 kHz there is only a small change in hearing level in 80-year-olds.

In young women there is a small improvement in mean hearing level at some frequencies (0.5 kHz in 30-year-olds, 1 kHz in 30- and 40-year-olds, 2 kHz in 30- and 40-year-olds, and 4 kHz in 40-year-olds). At 1 kHz 60-year-old women show no change in mean hearing level, but the spread of the percentiles decreases over time. This decrease in the spread is also evident in the 60-year-old women at 0.5 kHz though there is an increase in mean hearing level at this frequency. At 2 kHz in 50- and 60-year-olds, there is little change in mean hearing level over the follow-up period.

Figures 9 and 10 show that the proportion of subjects with a change in the average hearing level at 2, 3, and 4 kHz of greater than 10 dB varies with age. In 30-year-old men at all follow-up times up to 15 years, between 5% and 10% of screened subjects have a shift of at least 10 dB. The propor-

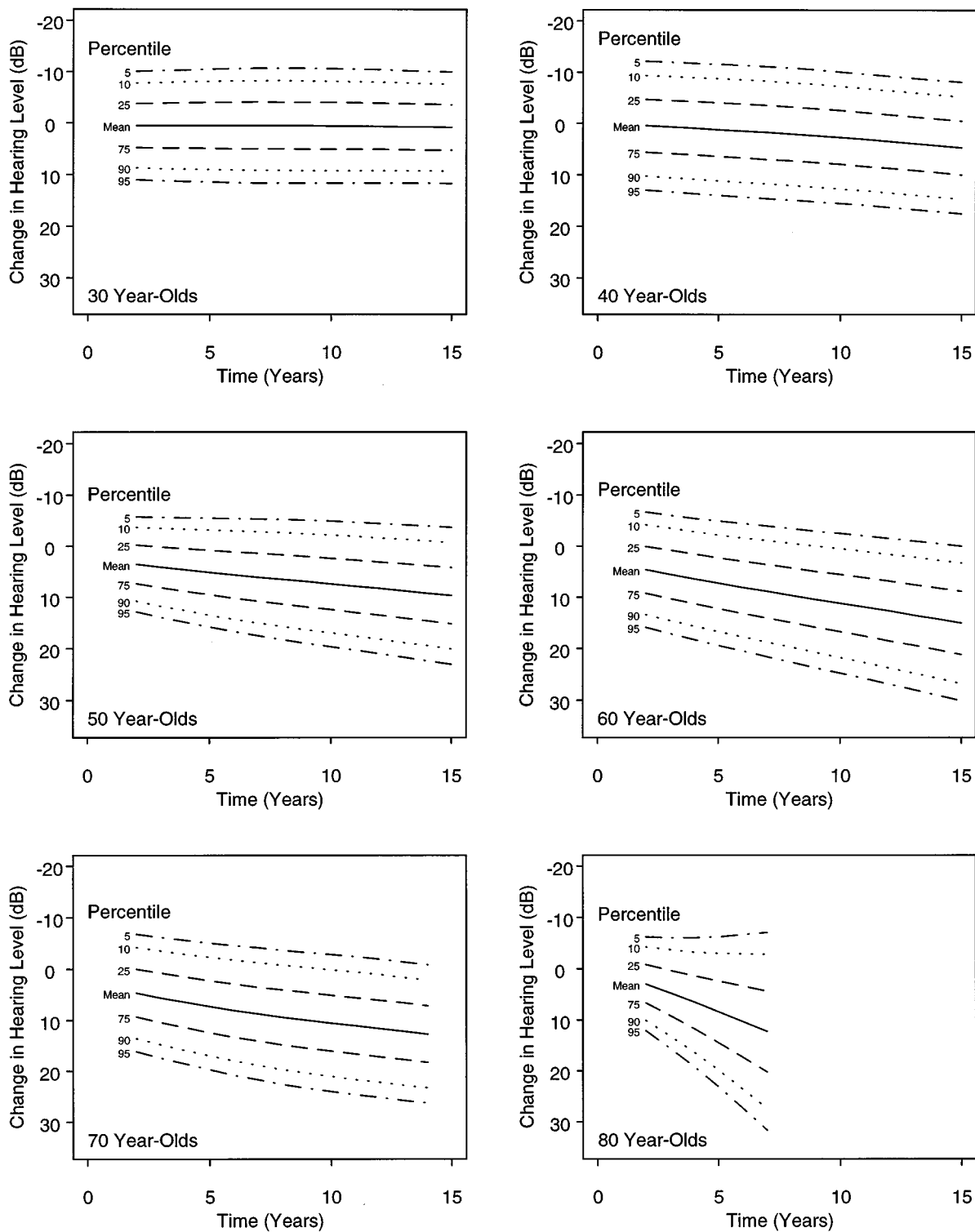


FIG. 9. Percentiles of longitudinal change in average hearing level in men at 2, 3, and 4 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

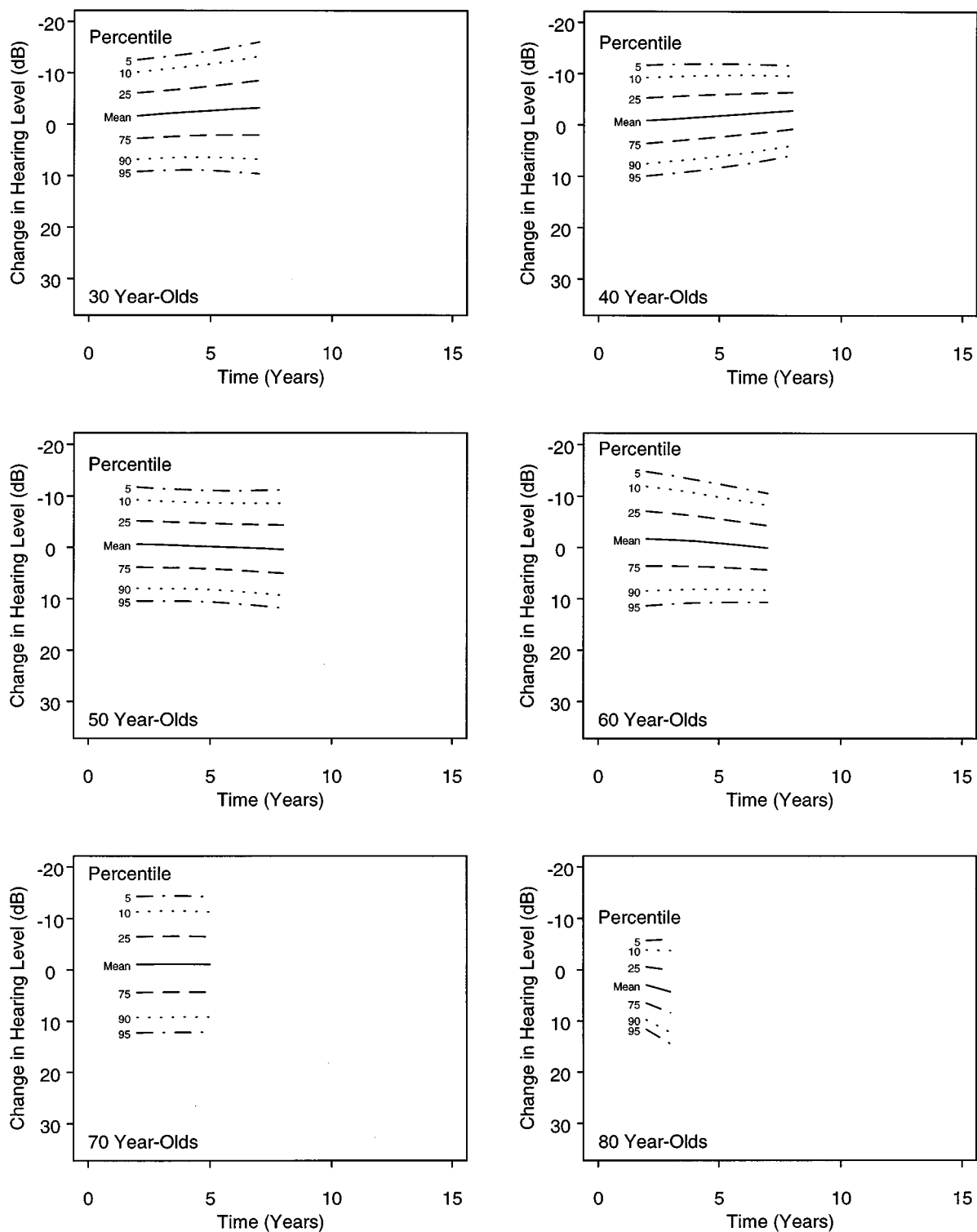


FIG. 10. Percentiles of longitudinal change in average hearing level in women at 2, 3, and 4 kHz who began the study in their 30s, 40s, 50s, 60s, 70s, or 80s.

TABLE V. Median number of participants in the age intervals for assessing cross sectional change for 0.5, 1, 2, and 4 kHz.

Age interval	Men	Women
22.5–27.4	23	13
25.0–29.9	21.5	28.5
27.5–32.4	33	35.5
30.0–34.9	44	35.5
32.5–37.4	39.5	32
35.0–39.9	36.5	30.5
37.5–42.4	49	32.5
40.0–44.9	50	30.5
42.5–47.4	43	21.5
45.0–49.9	40	19
47.5–52.4	34	29.5
50.0–54.9	33	31.5
52.5–57.4	26	21
55.0–59.9	39.5	24.5
57.5–62.4	56	30.5
60.0–64.9	53	32.5
62.5–67.4	66	30.5
65.0–69.9	72	31.5
67.5–72.4	68	45.5
70.0–74.9	74.5	50.5
72.5–77.4	72	44.5
75.0–79.9	71	35
77.5–82.4	75	32
80.0–84.9	70	26
82.5–87.4	51.5	16.5
85.0–89.9	30.5	...
87.5–92.4	14.5	...

tion increases with age and follow-up time. In 70-year-old men at two years after the initial measurement about 25% have had a change of 10 dB or more, and at 10 years of follow-up about 50% of participants have had a change of at least 10 dB. In 30- and 40-year-old women fewer than 5% of subjects exhibit an STS at all times. This proportion increases slowly with age but not as dramatically as in the men.

B. Cross-sectional change in hearing level

The graphs in Figs. 11 and 12 show that differences among the men and women are initially small but become larger as the age increases.

At 0.5 and 1 kHz the men and women show similar median cross-sectional hearing levels. The median hearing levels begin and end at about the same level. However, in men hearing level declines at a constant rate while in women, initially there are small decreases, but the hearing decline accelerates with increasing age. The percentiles at these reported frequencies are similar at young ages, but the men exhibit wider percentiles at higher ages.

At 2 and 4 kHz men and women in their 20s are again quite similar in median level though the upper percentiles are larger in the men. However, the hearing level in men de-

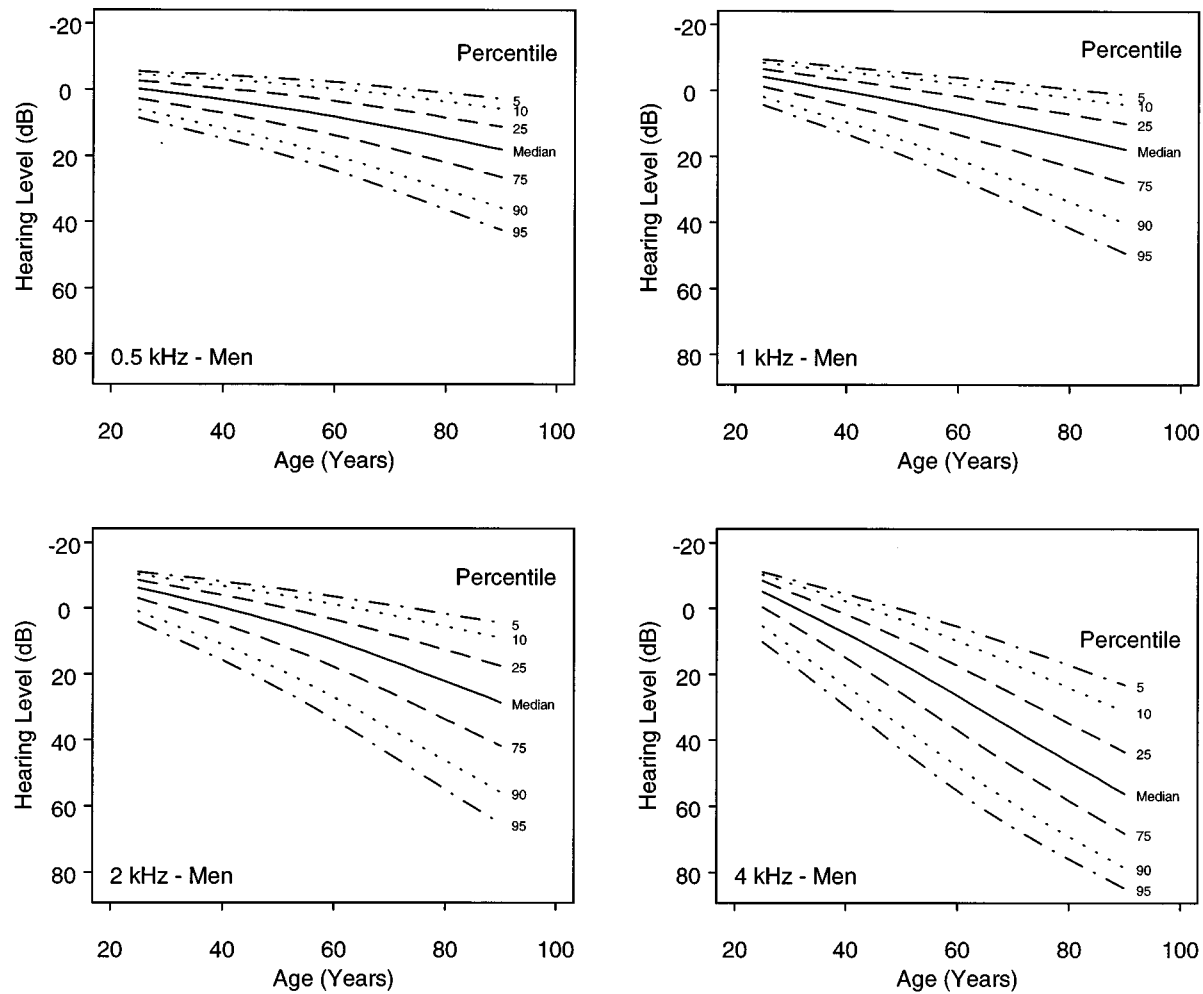


FIG. 11. Percentiles of cross-sectional change in hearing level in men at 0.5, 1, 2, and 4 kHz.

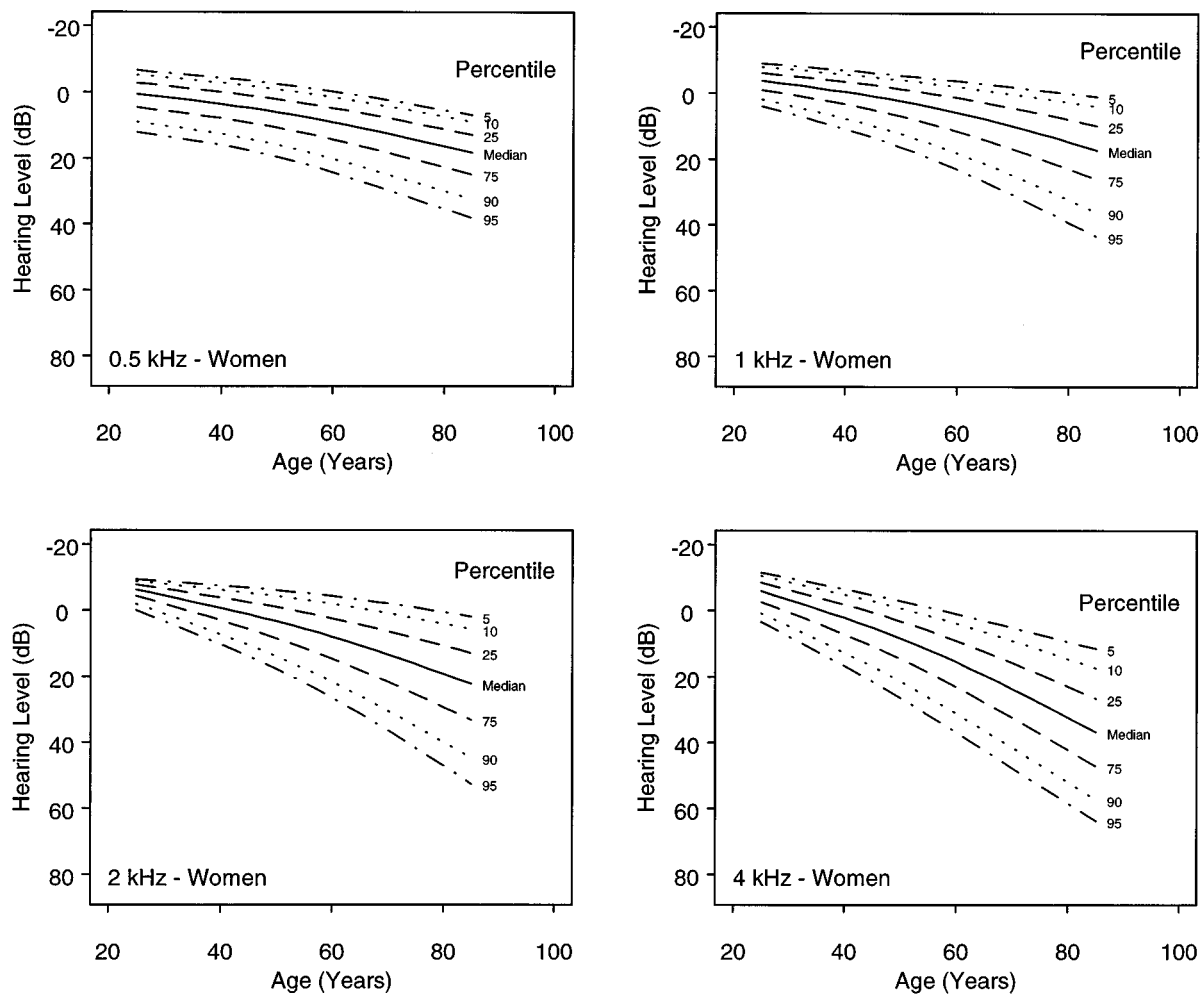


FIG. 12. Percentiles of cross-sectional change in hearing level in women at 0.5, 1, 2, and 4 kHz.

TABLE VI. Smoothed medians for cross-sectional change in hearing level in men.

Frequency	Age												
	25	30	35	40	45	50	55	60	65	70	75	80	90
0.5	-0.1	0.9	2.0	3.1	4.3	5.5	6.8	8.3	9.7	11.3	13.0	14.7	18.2
1	-4.1	-2.6	-1.2	0.3	1.9	3.5	5.1	6.9	8.7	10.5	12.3	14.1	17.8
2	-6.3	-4.3	-2.3	-0.2	2.0	4.4	7.0	9.8	12.8	15.8	19.0	22.2	28.6
4	-5.1	-0.9	3.3	7.6	12.1	16.7	21.5	26.5	31.6	36.6	41.6	46.5	56.2
Ave. 2, 3, 4	-5.5	-2.4	0.8	4.0	7.3	10.9	14.6	18.5	22.6	26.7	30.9	35.0	43.3

TABLE VII. Smoothed medians for cross-sectional change in hearing level in women.

Frequency	Age												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0.5	0.6	1.6	2.6	3.6	4.8	6.1	7.6	9.2	10.9	12.6	14.5	16.4	18.3
1	-3.8	-2.7	-1.6	-0.4	0.9	2.3	4.0	5.8	7.8	10.0	12.3	14.7	17.2
2	-6.3	-4.5	-2.6	-0.7	1.2	3.3	5.6	8.0	10.6	13.4	16.3	19.2	22.3
4	-5.8	-3.2	-0.5	2.2	5.2	8.3	11.8	15.5	19.4	23.6	27.9	32.3	36.7
Ave. 2, 3, 4	-6.0	-3.8	-1.6	0.7	3.1	5.7	8.5	11.6	14.8	18.2	21.8	25.5	29.2

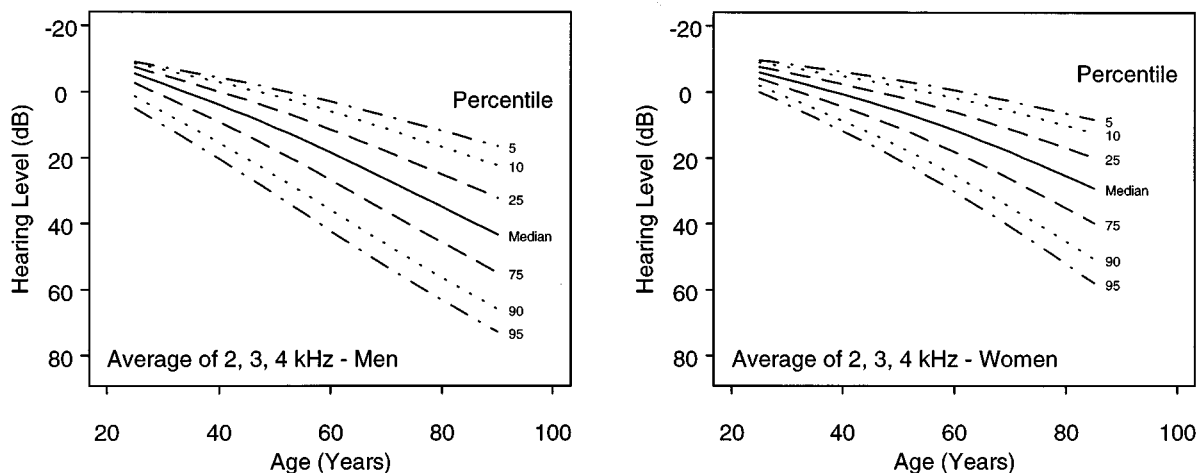


FIG. 13. Percentiles of cross-sectional change in average hearing level (at 2, 3, and 4 kHz) in men and women.

clines more rapidly and at a constant rate. In women the changes are initially small, and while the changes accelerate, the hearing distributions remain better in women than in men. The percentiles for men also have a larger spread than for women at all ages.

Figure 13 shows that the proportion of participants with

an average hearing level at 2, 3, and 4 kHz above 10 dB increases with age.

Figures 14 and 15 present the ISO median and percentile curves. A comparison with the BLSA percentiles (Figs. 11 and 12) show that in men, the ISO percentiles are similar to the BLSA percentiles at 0.5, 1, and 2 kHz up to 70 years of

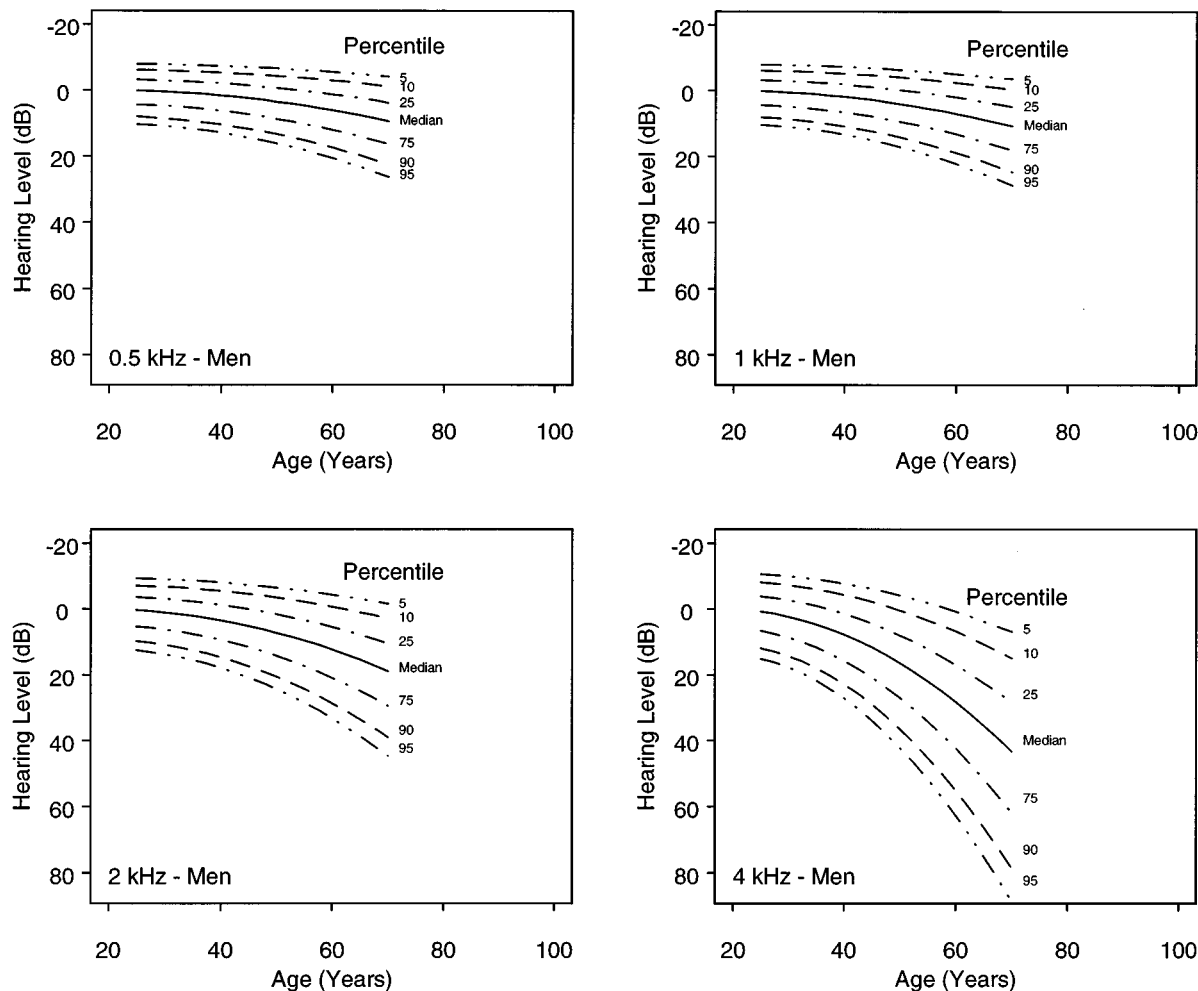


FIG. 14. The ISO percentiles of hearing level in men at 0.5, 1, 2, and 4 kHz.

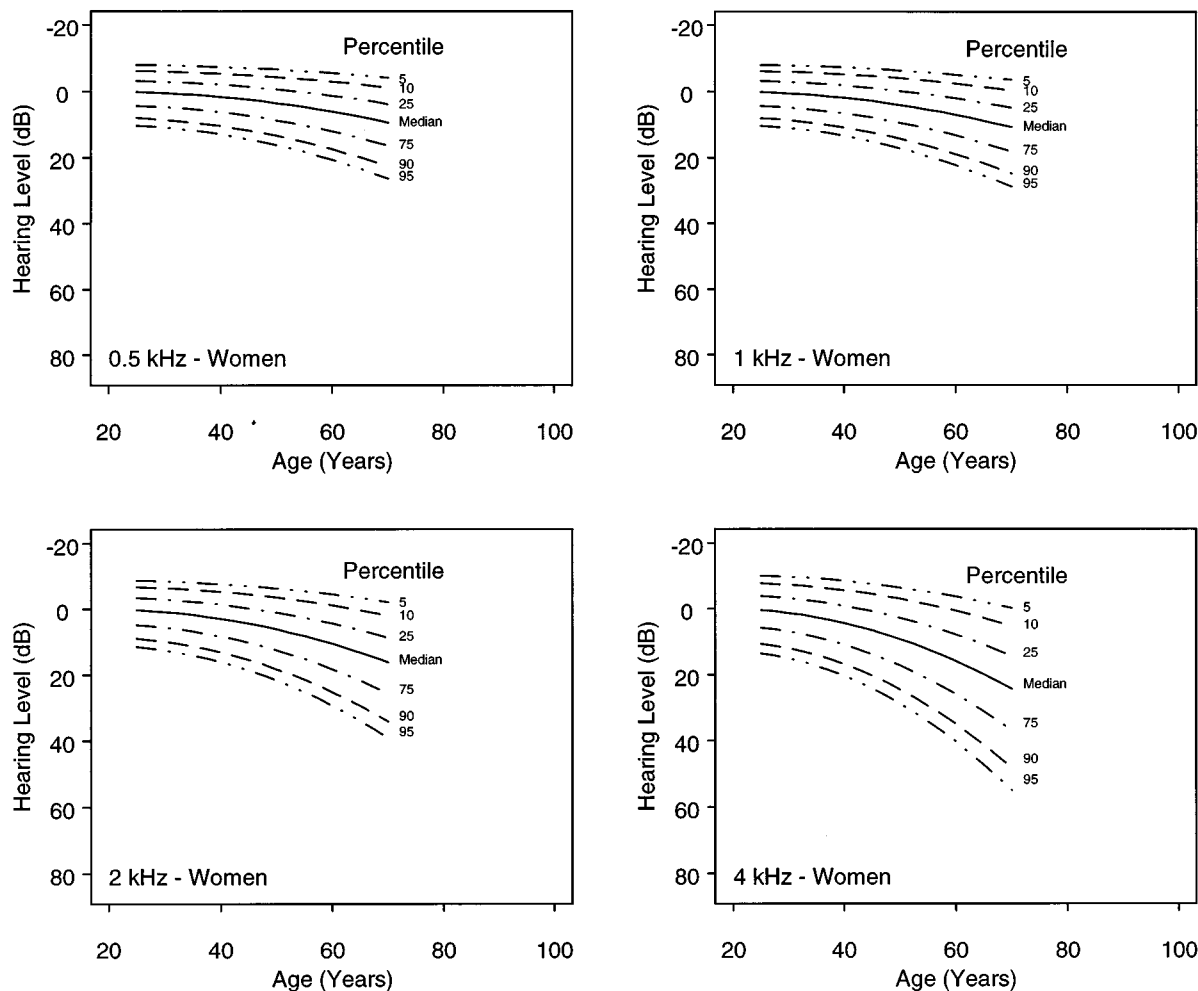


FIG. 15. The ISO percentiles of hearing level in women at 0.5, 1, 2, and 4 kHz.

age. At 4 kHz the ISO percentiles are more curved and drop off more sharply than the BLSA percentiles. In women, at 0.5 kHz the ISO curves are slightly better than the BLSA curves, at 1 kHz the percentiles are similar, and at 2 and 4 kHz the ISO percentiles are more spread out at all ages.

IV. CONCLUSIONS

We have constructed percentiles for hearing level at various ages and frequencies and for change in hearing level for a number of age groups and lengths of follow-up time. The percentile curves may be useful to provide a basis for determining whether individuals of particular ages exhibit abnormal hearing sensitivity by using the cross-sectional percentiles. Once an initial hearing level is determined, the change in hearing level may be monitored by using the longitudinal percentile curves. This would allow for the detection of unusual shifts in hearing level which may be early indicators of otologic disease, hearing impairment, or noise-induced hearing loss. These norms for subjects with no evidence of hearing problems may be useful to audiologists monitoring hearing levels in their patients or hearing levels in industrial workers whose employment setting may involve exposure to excessive noise levels. As noted previously, the

data should be directly comparable to data obtained from listeners using comparable self-tracking techniques. Application of the present findings to results obtained from manual audiometry should be conducted with some level of caution because thresholds obtained by self-recording techniques are generally slightly better than those obtained with manual techniques (Burns and Hinchcliffe, 1957; Knight, 1966; Harris, 1980). Nevertheless, the present findings indicate that in the sample of screened men the proportion exhibiting a STS increases with age and follow-up time, whereas in women the proportion remains low at all ages.

ACKNOWLEDGMENTS

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