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Age correction in monitoring audiometry: method to update OSHA age-correction tables to include older workers

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ABSTRACT

Objectives: The US Occupational Safety and Health Administration (OSHA) Noise Standard provides the option for employers to apply age corrections to employee audiograms to consider the contribution of ageing when determining whether a standard threshold shift has occurred. Current OSHA age-correction tables are based on 40-year-old data, with small samples and an upper age limit of 60 years. By comparison, recent data (1999–2006) show that hearing thresholds in the US population have improved. Because hearing thresholds have improved, and because older people are increasingly represented in noisy occupations, the OSHA tables no longer represent the current US workforce. This paper presents 2 options for updating the age-correction tables and extending values to age 75 years using recent population-based hearing survey data from the US National Health and Nutrition Examination Survey (NHANES). Both options provide scientifically derived age-correction values that can be easily adopted by OSHA to expand their regulatory guidance to include older workers.

Methods: Regression analysis was used to derive new age-correction values using audiometric data from the 1999–2006 US NHANES. Using the NHANES median, better-ear thresholds fit to simple polynomial equations, new age-correction values were generated for both men and women for ages 20–75 years.

Results: The new age-correction values are presented as 2 options. The preferred option is to replace the current OSHA tables with the values derived from the NHANES median better-ear thresholds for ages 20–75 years. The alternative option is to retain the current OSHA age-correction values up to age 60 years and use the NHANES-based values for ages 61–75 years.

Conclusions: Recent NHANES data offer a simple solution to the need for updated, population-based, age-correction tables for OSHA. The options presented here provide scientifically valid and relevant age-correction values which can be easily adopted by OSHA to expand their regulatory guidance to include older workers.

Strengths and limitations of this study

- Current Occupational Safety and Health Administration (OSHA) age-correction tables are based on a highly screened, small sample of data that is 40 years old, with an upper age limit of 60 years.
- The existing age-correction tables do not account for older people who are increasingly represented in noisy occupations or for the improvements in hearing thresholds reported in recent National Health and Nutrition Examination Survey (NHANES) data.
- This paper presents two options for updating age-correction tables, and for extending values to age 75 years using recent unscreened population-based hearing survey data from NHANES.
- Both options provide scientifically derived age-correction values that can be easily adopted by OSHA to expand their regulatory guidance to include older workers.
- The analysis relies upon the use of unscreened population-based hearing thresholds which include individuals with occupational noise exposure.

INTRODUCTION

The US Occupational Safety and Health Administration (OSHA)[1] requires workers who have daily time-weighted average noise exposures of 85 dBA or more to be enrolled in hearing conservation programmes that include annual audiometry. A threshold shift of 10 dB or more for the pure tone average of 2, 3 and 4 (PTA234) in either ear is considered a 'standard threshold shift' (STS). An STS that persists on retesting requires several actions:

- The worker must be counselled regarding the change in hearing;
- Hearing protection devices must be fitted or refitted;
- The STS may need to be recorded as a work-related injury.

OSHA offers optional age-correction tables (labelled as Table F-1 Males, Table F-2

Females, in the OSHA 29CFR 1910.95 Appendix F)[2] for employers who wish to consider the effects of ageing when analysing serial audiometric data. The OSHA age-correction tables are illustrated in figure 1. For example, consider a man whose right-ear baseline thresholds at age 20 years were 10, 15 and 15 dB hearing level at 2, 3 and 4 kHz, respectively; his baseline PTA234 is therefore 13.3 dB. Assume that several years later, at age 40 years, his right-ear PTA234 is now 25 dB. This threshold shift of 11.7 dB would be considered an STS without age correction. An employer who chooses to use age correction may consult the age-correction tables, which show expected values for PTA234 of 4 dB at age 20 years and 10 dB for age 40 years. The age-related shift of 6 dB may be subtracted from the threshold shift of 11.7 dB without age correction, resulting in an age-corrected shift of 5.7 dB, which would not constitute an STS.

OSHA's current age-correction tables have several drawbacks. They are based on the median thresholds of non-noise-exposed workers in a survey conducted by the US National Institute for Occupational Safety and Health (NIOSH).[3] This was a convenience sample of workers in a small number of worksites and cannot be considered representative of the US population. Sample sizes were limited to 380 men and 206 women.[3] Men aged 48–65 years (mean age of 55 years) were grouped together for a total of 76 men representing the oldest age category. Details on the age distribution of the 206 women were not reported. These sample sizes are not considered large enough to develop robust estimates of age effects. The current OSHA tables show expected hearing thresholds for ages 20–60 years for men and women. Hearing thresholds for ages above 60 years are not shown, probably because there were so few older

TABLE F-1 - AGE CORRECTION VALUES IN DECIBELS FOR MALES

Years	Audiometric Test Frequency (Hz)				
	1000	2000	3000	4000	6000
20 or younger	5	3	4	5	8
21	5	3	4	5	8
22	5	3	4	5	8
23	5	3	4	6	9
24	5	3	5	6	9
25	5	3	5	7	10
26	5	4	5	7	10
27	5	4	6	7	11
28	6	4	6	8	11
29	6	4	6	8	12
30	6	4	6	9	12
31	6	4	7	9	13
32	6	5	7	10	14
33	6	5	7	10	14
34	6	5	8	11	15
35	7	5	8	11	15
36	7	5	9	12	16
37	7	6	9	12	17
38	7	6	9	13	17
39	7	6	10	14	18
40	7	6	10	14	19
41	7	6	10	14	20
42	8	7	11	16	20
43	8	7	12	16	21
44	8	7	12	17	22
45	8	7	13	18	23
46	8	8	13	19	24
47	8	8	14	19	24
48	9	8	14	20	25
49	9	9	15	21	26
50	9	9	16	22	27
51	9	9	16	23	28
52	9	10	17	24	29
53	9	10	18	25	30
54	10	10	18	26	31
55	10	11	19	27	32
56	10	11	20	28	34
57	10	11	21	29	35
58	10	12	22	31	36
59	11	12	22	32	37
60 or older	11	13	23	33	38

TABLE F-2 - AGE CORRECTION VALUES IN DECIBELS FOR FEMALES

Years	Audiometric Test Frequency (Hz)				
	1000	2000	3000	4000	6000
20 or younger	7	4	3	3	6
21	7	4	4	3	6
22	7	4	4	4	6
23	7	5	4	4	7
24	7	5	4	4	7
25	8	5	4	4	7
26	8	5	5	4	8
27	8	5	5	5	8
28	8	5	5	5	8
29	8	5	5	5	9
30	8	6	5	5	9
31	8	6	6	5	9
32	9	6	6	6	10
33	9	6	6	6	10
34	9	6	6	6	10
35	9	6	7	7	11
36	9	7	7	7	11
37	9	7	7	7	12
38	10	7	7	7	12
39	10	7	8	8	12
40	10	7	8	8	13
41	10	8	8	8	13
42	10	8	9	9	13
43	11	8	9	9	14
44	11	8	9	9	14
45	11	8	10	10	15
46	11	9	10	10	15
47	11	9	10	11	16
48	12	9	11	11	16
49	12	9	11	11	16
50	12	10	11	12	17
51	12	10	12	12	17
52	12	10	12	13	18
53	13	10	13	13	18
54	13	11	13	14	19
55	13	11	14	14	19
56	13	11	14	15	20
57	13	11	15	15	20
58	14	12	15	16	21
59	14	12	16	16	21
60 or older	14	12	16	17	22

Figure 1 Illustration of Occupational Safety and Health Administration (OSHA) age-correction values in decibels, Table F-1 Males, Table F-2 Females, from Appendix F of OSHA 29CFR 1910.95.

participants in the NIOSH survey. In recent years, many workers continue in their jobs beyond the age of 60 years, when age-related threshold shifts not only continue but also accelerate. Thus, it is desirable for age-correction tables to include ages above 60 years. Finally, American adults of both sexes, aged 25–74 years, hear slightly better in recent surveys than in surveys conducted decades ago.[4 5] For all these reasons, the OSHA age-correction tables should be updated with newer and more complete data.

METHODS

Hoffman *et al*[4 5] tabulate median better-ear thresholds from the US National Health and Nutrition Examination Survey (NHANES) (1999–2004, 1999–2006) by sex, and by 10-year age bands (25–34, 35–44, 45–54, 55–64, and 65–74 years). These data represent hearing thresholds of more than 5000 persons and are considered representative of the unscreened non-institutionalised population of the USA during those years.

Using these data, regression analysis was used to predict new age-correction values for both men and women for ages 20–75 years. Regression equations began with simple linear fits of PTA versus age and proceeded to second-order and higher order polynomial fits until adjusted multiple R^2 failed to increase, using VassarStats online statistical software.[6]

OSHA's current tables (FI, F2) list age-correction values in separate columns for each test frequency, for example, 2, 3 and 4 kHz, at each age, for both sexes. The procedure assumes that age correction is performed separately for each of these three frequencies, and that the three age-corrected threshold shifts are then averaged to obtain a PTA234 value. A shift in PTA234 of 10 dB or greater constitutes an STS for the ear in question. However, it is easy to show algebraically that it is unnecessary to calculate threshold shifts for all three frequencies separately. Since the three threshold shifts at 2, 3 and 4 kHz are eventually averaged in the STS calculation, the identical result is obtained (much more simply) by using only a single column of age-correction factors for each sex, representing PTA234. Thus, the age-correction table we propose has only two columns: one for men and one for women. In addition, we show a hybrid table in which the existing OSHA age-correction data are retained up to age 60 years, with the NHANES data used for extending the tables up to age 75 years.

RESULTS

Figures 2 and 3 show the NHANES better-ear median thresholds for 2, 3 and 4 kHz, for each of the age bands mentioned above (nominally, 30, 40, 50, 60 and 70 years of age) for men and women, respectively. As in all such surveys, hearing thresholds not only increase with age, but also display acceleration. In other words, the rate of change increases with age. Data such as these are typically fit to quadratic equations in which hearing threshold is a function of both age and $(age)^2$. The best-fit quadratic functions, as well as the separate points representing NHANES age-group medians, are also illustrated in each figure. Note that the vertical axes for figures 2 and 3 are different (0–60 dB for men vs 0–30 dB for women), because at older ages, men hear much worse than women.

Using the polynomial best-fit equations, age-correction values for ages 20–75 years were calculated for PTA234 (figure 4). For men, a quadratic fit was optimal, with an adjusted multiple R^2=0.9999 that did not increase with higher order fits. For women, a cubic fit produced the

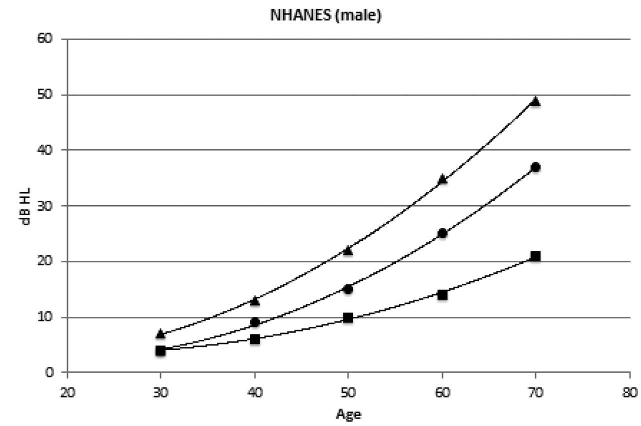

Figure 2 Median thresholds for 2 kHz (squares), 3 kHz (circles) and 4 kHz (triangles) are shown for men of five different age groups with nominal ages as shown (see text), from the National Health and Nutrition Examination Survey (NHANES) audiometric surveys, 1999–2006. The lines are quadratic fits to the data.

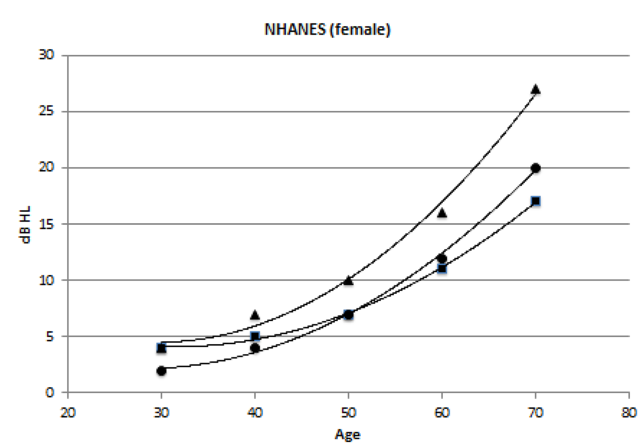

Figure 3 Median thresholds for 2 kHz (squares), 3 kHz (circles) and 4 kHz (triangles) are shown for women of five different age groups with nominal ages as shown (see text), from the National Health and Nutrition Examination Survey (NHANES) audiometric surveys, 1999–2006. The lines are quadratic fits to the data.

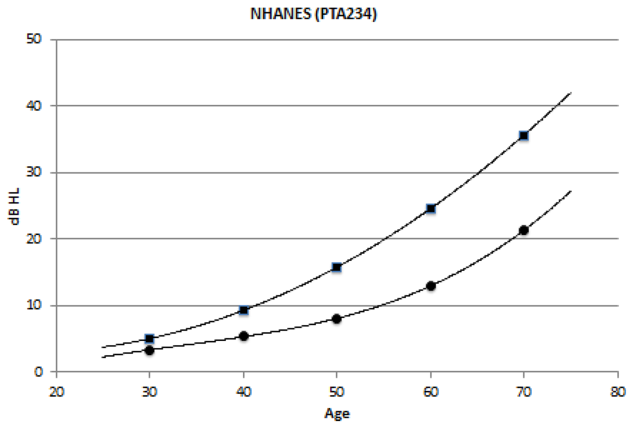

Figure 4 Median thresholds for the 2-kHz, 3-kHz and 4-kHz pure-tone average are shown for men (squares), and women (circles) of five different age groups with nominal ages as shown (see text), from the National Health and Nutrition Examination Survey (NHANES) audiometric surveys, 1999–2006. The lines are quadratic (men) and cubic (women) fits to the data.

best fit, with adjusted multiple R^2=0.9999. The lines shown in figure 4 have the equations:

$$\text{Men: PTA234} = 0.0114(\text{age})^2 - 0.3762(\text{age}) + 6.019 \quad (1)$$

$$\text{Women: PTA234} = 0.000222(\text{age})^3 - 0.0262(\text{age})^2 + 0.9563(\text{age}) - 10.99 \quad (2)$$

Table 1 contains the two options for updating the current OSHA age-correction tables and their respective age-correction values for men and women.

A complete replacement of the current OSHA age-correction tables using the quadratic curves generated from the NHANES data for ages 20–75 years is shown in the second and third columns of table 1. The new values are based on equations (1) and (2) shown above, but with all values rounded to the nearest integer decibel.

An alternative option is the hybrid approach, shown in columns four and five of table 1. The hybrid retains the current OSHA data up to age 60 years and uses the new NHANES data to extend the tables to age 75 years with a smooth transition at age 60 years. Making a smooth transition requires only three steps: (1) convert the current tables into PTA234 values; (2) compare the age 60 years values from the OSHA tables with the NHANES age 60 years values and (3) add (subtract) the age 60 years differences to (from) the NHANES values for ages 60–75 years. Fortunately, the age 60 years differences between OSHA and NHANES are small. For men, the age 60 years median PTAs are 23 dB for OSHA and 24 dB for NHANES. Accordingly, the recommended extension-table values for ages 61–75 years are 1 dB less than in table 1. For women aged 60 years, the difference was 2 dB in the opposite direction: 15 dB for OSHA vs 13 dB for NHANES. The entries for ages 20–60 years are

Table 1 Two options for a new OSHA age-correction table; one using only NHANES data, the other using hybrid data (current OSHA values to age 60 years in bold font, NHANES data from age 61 to 75 years)

	(Only NHANES data)		(Hybrid data: see text)	
Age (years)	Men	Women	Men	Women
20	3	1	**4**	**3**
21	3	1	**4**	**4**
22	3	1	**4**	**4**
23	3	2	**4**	**4**
24	4	2	**5**	**4**
25	4	2	**5**	**4**
26	4	2	**5**	**5**
27	4	3	**6**	**5**
28	4	3	**6**	**5**
29	5	3	**6**	**5**
30	5	3	**6**	**5**
31	5	4	**7**	**6**
32	6	4	**7**	**6**
33	6	4	**7**	**6**
34	6	4	**8**	**6**
35	7	4	**8**	**7**
36	7	5	**9**	**7**
37	8	5	**9**	**7**
38	8	5	**9**	**7**
39	9	5	**10**	**8**
40	9	5	**10**	**8**
41	10	6	**10**	**8**
42	10	6	**11**	**9**
43	11	6	**12**	**9**
44	12	6	**12**	**9**
45	12	7	**13**	**9**
46	13	7	**13**	**10**
47	14	7	**14**	**10**
48	14	7	**14**	**10**
49	15	8	**15**	**10**
50	16	8	**16**	**11**
51	16	8	**16**	**11**
52	17	9	**17**	**12**
53	18	9	**18**	**12**
54	19	10	**18**	**13**
55	20	10	**19**	**13**
56	21	11	**20**	**13**
57	22	11	**20**	**14**
58	23	12	**22**	**14**
59	24	12	**22**	**15**
60	24	13	**23**	**15**
61	25	14	24	16
62	27	14	26	16
63	28	15	27	17
64	29	16	28	18
65	30	17	29	19
66	31	18	30	20
67	32	18	31	20
68	33	19	32	21
69	34	20	33	22
70	36	21	35	23
71	37	22	36	24
72	38	24	37	26

Continued

Table 1 Continued

Age (years)	(Only NHANES data) Men	Women	(Hybrid data: see text) Men	Women
73	39	25	38	27
74	41	26	40	28
75	42	27	41	29

NHANES, National Health and Nutrition Examination Survey; OSHA, Occupational Safety and Health Administration.

based on OSHA's age-correction table (simply averaging the values for 2, 3 and 4 kHz, then rounding to integer values), while the entries for ages 61–75 years are based on the NHANES data (minus 1 dB for men, plus 2 dB for women).

DISCUSSION

OSHA's current age-correction tables are based on a highly screened, small sample of data that is 40 years old with an upper age limit of 60 years. We have devised a methodology to update the age-correction tables using recent hearing threshold data from a robust sample of the NHANES (1999–2006) dataset and to extend the age-correction values to age 75 years to account for older workers. We describe two scientifically valid methods for updating the OSHA age-correction tables using recent NHANES median better-ear thresholds pure tone averages for 2-kHz, 3-kHz and 4-kHz test frequencies. Both methods extend the age-correction values to age 75 years to address the trend of older workers remaining longer in the workforce. The decision to create two options is based on the extensive rule-making process within OSHA. While a complete update of the age-correction tables would be both simpler and scientifically more valid, we offer an alternative hybrid table in which NHANES data are used to extend the current OSHA tables to age 75 years.

The decision to use NHANES data is based on its recent and large population-based samples for both sexes and for ages that extend well beyond the current OSHA tables. Although one could conceivably use another national source of hearing threshold data, NHANES data have been well studied and are regarded as a robust nationally representative sample.[4] While using the unscreened NHANES data for comparison with people with occupational noise exposure is reasonable, we acknowledge a few caveats.

- The NHANES sample includes people who have had occupational noise exposure; if occupational noise effects have an appreciable contribution to median hearing thresholds, and if those effects could be removed, the median thresholds would likely be lower (better) at most frequencies.
- However, simply removing people who report a history of occupational noise exposure removes much more than the effects of occupational noise, because people in noisy jobs, when compared with the general population, have higher prevalences of several other independently important hearing-loss risk factors, such as low socioeconomic status, white race, recreational shooting, other non-occupational noise, heavy smoking, and diabetes.[7] The ideal comparison group for industrial workers would be similar to the study group in all risk factors other than the exposure in question (usually noise), but such comparison groups are unavailable. Dobie and Agrawal[8] argue that an unscreened population sample is usually more appropriate for comparison with occupationally exposed workers than a sample from which occupationally exposed people have been removed.

We consider the use of better-ear thresholds, rather than binaural averages, appropriate for comparison with a worker's better ear, but acknowledge that this may result in undercorrection for age effects when compared with a worker's worse ear.

An important caveat about median-based age correction: there is an implicit assumption that age-related hearing loss is the same for every man or woman. In fact, the tabled numbers are simply the median, or 50th percentile, values from a particular survey. Within the survey group, half of participants had better thresholds, and half had worse thresholds, than those reported as the medians. This means that age correction will sometimes overcorrect, and sometimes undercorrect, for the effects of age. After age correction, some threshold shifts that have actually been caused by noise will no longer be counted as STS (false negatives). And some threshold shifts that were actually caused entirely by ageing will still be counted as STS (false positives). For this reason, and also because audiometric variability will inevitably create many spurious STS, age correction can never eliminate false positive STS, even in a population with absolutely no noise exposure.

In summary, the current OSHA age-correction tables should be replaced with more relevant hearing thresholds that extend up to age 75 years to reflect the current trends of older workers in the workforce. We recommend a complete replacement of the current OSHA age-correction tables using the values derived from the NHANES median better-ear thresholds for ages 20–75 years. Alternatively, a hybrid table using OSHA values up to age 60 years, and NHANES values for ages 61–75 years (adjusted slightly to ensure a smooth transition at age 60 years) is presented as a good second choice. This recommended update to the OSHA age-correction tables provides more complete and accurate guidance for employers who opt to apply age corrections to employee audiograms to consider the contribution of ageing when determining whether a standard threshold shift has occurred. We believe this information can be of global interest in cases where occupational health professionals working outside the USA may choose to follow OSHA standards, if the OSHA standards are more conservative than in-country standards, or if in-country standards do not exist.

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Competing interests NCW is currently employed by ExxonMobil Biomedical Sciences, Inc. RAD is a paid consultant.

Provenance and peer review Not commissioned; externally peer reviewed.

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