Comparisons with databases can help professionals interpret hearing test results with respect to a suitable reference group. A mildly-screened population is frequently the most appropriate reference group. The database currently used for this purpose relies heavily on data obtained by the US Public Health Service in the early 1960s, and separate analyses were not conducted by ethnic group.

In this study, we used data from the National Health and Nutrition Examination Survey (NHANES) to identify cumulative distribution functions for pure tone thresholds by age, gender, frequency, and ethnicity.

**Method**

Participants (ages 12-69) contributing audiometric data to NHANES were included in the study. Participants with abnormal tympanometry or a history of occupational noise exposure were excluded. Non-Hispanic black, non-Hispanic white, and Mexican-American ethnic groups were included because these groups had adequate sample sizes for analysis. Other ethnic groups were not included, leaving a total sample of 3058 women and 2096 men.

Cumulative pure tone threshold distributions, accounting for the complex sample design of NHANES, were obtained at each frequency and for each ear using SPSS. These 504 distributions were individually fitted with 5-parameter reverse asymmetric sigmoid curves using TableCurve2D.

**Demographic trends in parameters**

Associations between curve parameters and age, ethnicity, and frequency were assessed for men using 3-way ANOVA. Many aspects of the cumulative distributions differed by these factors, suggesting a need to account for the distribution shape as well as the median when accounting for demographic factors.

No substantial effects (adjusted $R^2 < .1$) were observed for the 0 (intercept) or $b$ (asymptote) parameters.

The $c$ (location) parameter was well predicted (adjusted $R^2 = .76$) by age, frequency, and ethnicity main effects, and age*ethnicity and age*frequency interactions. Main effects of age were unsurprising, and effects of frequency matched expectations based on typical audiometric threshold functions (1 kHz best, 6 kHz worst). Non-Hispanic blacks had better location parameter values than Mexican-Americans, and non-Hispanic whites were not significantly different from either group.

The $d$ (slope) parameter differed modestly (adjusted $R^2 = .18$) by age and frequency.

Slopes were flatter for the 60-69 year olds than any other group, and slopes at 8 kHz were flatter than at 0.5 or 2 kHz.

The $e$ (asymmetry) parameter was moderately well-predicted by the ANOVA model (adjusted $R^2 = .50$), and only the ethnicity main effect failed to reach significance as a predictor. The prediction was dominated by (2- and 3-way) interaction terms.

The practicality of a regression-based prediction of parameter values revealed that the median point can be predicted accurately, but the spread of data around the median cannot. For example, regression based prediction of the distribution function of non-Hispanic white men (30-39, left ear, 4 kHz) matched the median fitted function within 1 dB. However, the predicted interquartile range was considerably smaller than the fitted function (2 dB v. 21 dB).

**Accuracy of fitted values**

The 5-parameter reverse asymmetric sigmoid function fit the observed cumulative distributions very well. Over 99% of the coefficients of determination ($r^2$) were > .97, with the worst fit shown here.

This group, 50-59 year old Mexican-American males, had the fewest samples in the data set (unweighted n=30), which can be expected to lead to lower precision of cumulative distribution points and poorer fit.

**Conclusions**

The results of this study can be used to compare observed thresholds to a reference population. The reference populations currently reported in ANSI S3.44 are compromised because they failed to account for the effects of ethnicity, assumed a gaussian distribution of hearing threshold levels, failed to include 8 kHz, and included only points on the distribution rather than a parametric treatment of the cumulative distribution function, in addition to cohort effects and sampling limitations.

This study demonstrates that the

- 5-parameter asymmetric reverse sigmoid function can fit cumulative hearing threshold distributions
- location, slope, and asymmetry are all affected by demographic factors, often in a complex way
- differences in demographic factors are best addressed by using distribution functions specific to the demographic profile of the listener.

**References**


**Acknowledgements**

The authors thank Howard Hoffman (NIDCD), Bill Murphy (NIOSH), and Robert Dobie (UTHSCSA) for their assistance and many helpful comments on this project.

**Availability**

Curve parameters, distribution points, and a Matlab function for calculating the reverse asymmetric sigmoid function are available electronically from greg.flamme@wmich.edu.