Effects of Pre-existing Hearing Loss and Gender on Proposed ANSI S12.13 Outcomes for Characterizing Hearing Conservation Program Effectiveness: Preliminary Investigation

Nathan E. Amos*  
Thomas H. Simpson†

Abstract

Draft American National Standard "Evaluating the Effectiveness of Hearing Conservation Programs" identifies potentially important links between audiometric threshold variability outcomes and occupational hearing conservation program (HCP) practices. Unacceptable threshold variability in annual audiograms may identify poor testing practices and temporary threshold shifts. This preliminary investigation reveals pre-existing hearing loss to be a potentially important confounding variable to interpreting ANSI S12.13 outcomes. Poorer hearing groups in this study consistently yielded greater threshold variability (i.e., "poorer" HCP performance) than better hearing groups. Gender may also be a confounding variable, however, to a far lesser degree. HCP managers should exercise caution when interpreting relative ANSI S12.13 outcomes among HCPs differing in baseline hearing sensitivity. Potential causes for these findings are discussed, and implications for future research are identified.

Key Words:  Percent better or worse sequential, percent worse sequential, standard deviation of difference thresholds

Prevention of significant occupational noise-induced hearing loss should be the primary goal of industrial hearing conservation programs (HCPs) (Royster et al, 1982). Occupational Safety and Health Administration (OSHA) regulations define minimum standards for HCPs in industry, but these regulations give no formal guidance for determining program effectiveness (OSHA, 1983).

The need for objective HCP performance data is well documented (Melnick, 1984; Royster and Royster, 1954, 1986a, 1990; Stewart, 1988; Suter, 1989). Royster and Royster (1988) reported that HCP professionals need objective performance data to make decisions about HCP policies, to achieve and maintain adequate employee protection, to justify resource allocations, and to motivate supervisors and employees. Additionally, they reported that such information could be useful to regulatory compliance officers.

Draft American National Standard


ANSI S12.13 protocols are based on variability of hearing threshold level (HTL) measurements between sequential pairs of annual audiograms (ANSI, 1991). Working Group S12/WG12 reported that the procedures are easily applicable, demonstrate the greatest discrimination ability between HCPs differing in performance, and avoid many problems inherent in other evaluation methods (ANSI, 1991).

The ANSI S12.13 draft standard recommends three protocols to determine year-to-year audiometric variability:

1. Percent worse sequential (%Ws): The population percentage demonstrating a 15 dB or greater change toward worse hearing at any test frequency (0.5–6 kHz) in either ear between two sequential audiograms.
2. Percent better or worse sequential (%BWs): The population percentage demonstrating a 15 dB or greater change toward either better or worse hearing at any test frequency (0.5-6 kHz) in either ear between two sequential audiograms.

3. Standard deviation of differences in HTLs (SDD): The standard deviation of differences between binaurally averaged HTLs between two sequential audiograms, calculated at individual test frequencies from 0.5 to 6 kHz and at multiple frequency averages of 0.5 to 3 kHz, 2 to 4 kHz, and 3 to 6 kHz (ANSI, 1991).

ANSI Working Group S12WG12 determined significantly less audiometric threshold variability in “control” HCPs with known excellent practices versus “noncontrol” HCPs, about which less was known. Criterion ranges of acceptable, marginal, and unacceptable audiometric variability developed from control HCPs are published in the draft standard. Excessive audiometric variability is associated with poor quality testing and the possibility that audiometric data may be contaminated by temporary threshold shift (TTS). If testing environment and procedures can be ruled out as contributing to unacceptable levels of audiometric variability, then insufficient hearing protection practices are implicated (ANSI, 1991).

Population age, gender, race, pre-existing hearing status, and degree of noise exposure may influence ANSI outcomes (ANSI, 1991); however, the draft standard reports criterion HCP performance ranges for males only, without consideration of additional potentially confounding variables. It would be useful to HCP managers for additional research data to address potential differences in ANSI outcomes for demographically diverse populations.

Because ANSI S12.13 outcomes are purportedly sensitive to TTS, pre-existing hearing loss is a potentially critical variable worthy of further examination. Laboratory studies of TTS, for example, have demonstrated less TTS in ears with pre-existing hearing loss than in normal ears (Melnick, 1978). Furthermore, field data confirm that rates of occupationally noise-induced hearing loss are faster for more sensitive ears (Taylor et al, 1969). Franks et al (1989) found baseline hearing status to be a factor in determining percentages of hearing declines on subsequent annual audiograms, and Chen and Pell (1989) reported increased test-retest threshold variability for groups of employees with poorer baseline hearing levels.

Gender is another potentially critical variable worthy of further consideration. Research has indicated gender differences in auditory sensitivity in both nonoccupationally noise-exposed and occupationally noise-exposed populations (Bunch and Raiford, 1931; Royster et al, 1980). Furthermore, federal noise and hearing conservation regulations account for gender differences in presbycusis (OSHA, 1983). Additional data suggest subtle gender differences in audiometric threshold stability (Baker and Weiler, 1977).

This study was undertaken to investigate the nature and extent to which differences in pre-existing hearing loss and gender may affect proposed ANSI S12.13 outcomes. Results will provide HCP managers with useful information to make relative performance comparisons of HCPs differing demographically (i.e., HTL and gender).

METHOD

Audiometric Data

The audiometric data utilized in this investigation were obtained from the database of over 140,000 serial audiograms compiled by Royster and Royster (1986b). These are the same data utilized in development of the draft standard. The database is currently in the public domain and available in magnetic format from National Technical Information Service (NTIS), Springfield, VA.

Selection of Audiometric Records

Audiometric records of 1268 subjects (660 females and 608 males) were selected according to baseline hearing threshold levels (HTLs) from three ANSI S12.13 control HCPs (ANSI001, ANSI002, and ANSI005) in the database. No records meeting the selection criteria were eliminated, and sample size was considered sufficient to be representative of the available pool of control HCP data.

Control HCP records were utilized because of reported excellent practices exhibited by these programs (ANSI, 1991). Thus, any observed effects would not likely be contaminated by audiometric threshold variability associated with poor testing practices. Furthermore, audiometric variability outcomes are reportedly similar for exposed and unexposed control employees; therefore, ANSI S12.13 outcomes for gender and hearing level groups would not likely be contaminated by group differences in noise exposure (ANSI, 1991).
Subjects were classified into one of three hearing level groups according to binaural averages of their baseline HTLs from 0.5 to 6 kHz. Group 1 subjects demonstrated binaural mean HTLs greater than -5 and less than or equal to 5 dB; group 2 subjects had a mean greater than 5 and less than or equal to 15 dB HTL; and group 3 subjects had a mean greater than 15 and less than or equal to 25 dB HTL.

Records were additionally classified according to gender and occupational noise exposure. Subjects were required to have a minimum of two sequential audiograms. Initial (i.e., first chronologically) audiograms were arbitrarily classified as baselines, and only records where the second serial test fell within 6 to 18 months of baseline were selected to fulfill draft standard data requirements (ANSI, 1991). Time-weighted-average (TWA) noise exposures were accounted for by further classifying records demonstrating either low (less than 75 dBA) or high (85–99 dBA) occupational noise exposure.

ANSI S12.13 outcomes were calculated for hearing level, gender, and exposure groupings. All significance testing was performed at the 0.05 level of confidence unless otherwise indicated.

**RESULTS**

Table 1 reports mean and standard deviation age, baseline HTLs (0.5–6 kHz), and binaural hearing shifts (test 1 to test 2) for all subject groupings. Subjects with the best baseline hearing levels (HTL group 1) demonstrated the greatest hearing declines from test 1 to test 2, while subjects with poorest baseline hearing levels (HTL group 3) systematically demonstrated HTL “improvements” from baseline to test 2. A one-way ANOVA for hearing shifts as a function of hearing level group (collapsed across gender and noise exposure categories) was performed. Tukey post-hoc comparisons indicated all mean shifts to be significantly different from one another.

Table 2 reports ANSI S12.13 outcomes as a function of noise exposure, gender, and baseline HTL group. Outcomes for the 11 ANSI S12.13 protocols are displayed in each column, with each row representing a different noise exposure (low or high) by gender by hearing threshold level (HTL) group combination. As expected, differences in ANSI S12.13 outcomes were found to be rather small as a function of noise exposure groups (ANSI, 1991); therefore, outcomes were recalculated for hearing level and gender groups collapsed across noise exposure classifications, and chi-square analyses were performed to account for potential differences in occupational noise exposure for hearing level and gender groups.

**Hearing Level Effects**

Table 1 summarizes SDD outcomes as a function of baseline HTL group collapsed across gender and noise exposure categories. Outcomes increased from HTL group 1 to 3 for all SDD protocols; increases were monotonic as a function of HTL group for eight of nine SDD protocols. The largest increase in magnitude of SDD outcomes

### Table 1: Mean and Standard Deviation Age, Baseline HTLs, and Binaural Hearing Shifts from Baseline Audiogram to Test 2 as a Function of Noise Exposure, Gender, and HTL Group

<table>
<thead>
<tr>
<th>TWA</th>
<th>Sex</th>
<th>HTL</th>
<th>n</th>
<th>Test 1</th>
<th>M</th>
<th>STD</th>
<th>Test 1</th>
<th>M</th>
<th>STD</th>
<th>Test 1–Test 2</th>
<th>M</th>
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<tr>
<td>Low</td>
<td>F</td>
<td>1</td>
<td>69</td>
<td>24.1</td>
<td>7.1</td>
<td></td>
<td>3.4</td>
<td>1.6</td>
<td></td>
<td>2.1</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>F</td>
<td>2</td>
<td>187</td>
<td>28.5</td>
<td>9.5</td>
<td></td>
<td>8.6</td>
<td>2.5</td>
<td></td>
<td>0.3</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>F</td>
<td>3</td>
<td>26</td>
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<td>11.7</td>
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<td>18.3</td>
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<tr>
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<td>M</td>
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<td>0.9</td>
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<tr>
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<td></td>
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<tr>
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<td>18.9</td>
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<td>-0.2</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>

F = female; M = male; a negative number indicates improved hearing.
Table 2  ANSI S12.13 Outcomes as a Function of Noise Exposure, Gender, and HTL Group

<table>
<thead>
<tr>
<th>TWA</th>
<th>Sex</th>
<th>HTL</th>
<th>n</th>
<th>.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>5123</th>
<th>234</th>
<th>346</th>
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<th>%BWs</th>
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<tbody>
<tr>
<td>L</td>
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<td>1</td>
<td>69</td>
<td>3.6</td>
<td>3.2</td>
<td>3.2</td>
<td>4.3</td>
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<td>3.5</td>
<td>4.1</td>
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<tr>
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<td>187</td>
<td>4.9</td>
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<td>5.3</td>
<td>5.6</td>
<td>7.1</td>
<td>3.1</td>
<td>3.8</td>
<td>4.8</td>
<td>16</td>
<td>27</td>
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<tr>
<td>L</td>
<td>F</td>
<td>3</td>
<td>26</td>
<td>8.7</td>
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<td>8.2</td>
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<tr>
<td>L</td>
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<td>3.8</td>
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<tr>
<td>L</td>
<td>M</td>
<td>2</td>
<td>175</td>
<td>4.1</td>
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<td>4.3</td>
<td>21</td>
<td>26</td>
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<tr>
<td>L</td>
<td>M</td>
<td>3</td>
<td>81</td>
<td>5.6</td>
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<td>7.0</td>
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<tr>
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<td>5.3</td>
<td>5.6</td>
<td>7.1</td>
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<td>4.7</td>
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<td>81</td>
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<td>5.9</td>
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<td>3.8</td>
<td>5.1</td>
<td>5.6</td>
<td>21</td>
<td>41</td>
</tr>
</tbody>
</table>

L = low noise exposure; H = high noise exposure. F = female; M = male.

from HTL group 1 to 3 occurred at 3 kHz, with an 82 percent increase, and the smallest increase occurred at 0.5 kHz, with a 23 percent increase.

Figure 2 summarizes %Ws and %BWs outcomes as a function of baseline HTL group collapsed across gender and noise exposure categories. Results revealed an increase in variability outcomes from HTL group 1 to 3 for the %Ws measure and a monotonic increase in variability outcomes for the %BWs measure. The increase in outcome magnitude from HTL group 1 to HTL group 3 was 9 percent for the %Ws measure and 116 percent for the %BWs measure.

The mean percent increase in outcome magnitude from HTL group 1 to HTL group 3 across all 11 ANSI S12.13 measures in Figures 1 and 2 was 50 percent. Additionally, chi-square contingency outcomes indicated no significant relationship between HTL group and noise exposure group. Thus, the marked hearing level effect observed was likely not confounded by differing occupational noise exposures across hearing level groups.

Gender Effects

Figure 3 summarizes SDD outcomes as a function of gender collapsed across baseline hearing level and noise exposure categories. Results revealed slightly greater variability outcomes for females in six of nine protocols. The largest female increase in outcome magnitude was 11 percent, at 0.5 kHz.

Figure 4 summarizes %Ws and %BWs outcomes as a function of gender collapsed across baseline hearing level and noise exposure categories. Results again revealed slightly greater female variability outcomes for both measures. The %Ws revealed a 15 percent increase, while the %BWs revealed a 9 percent increase.

The mean percent increase in outcome magnitude for females across all 11 ANSI S12.13 measures in Figures 3 and 4 was a modest 3 percent. Additionally, chi-square contingency outcomes indicated a significant relationship between gender and noise exposure group. Females demonstrated greater audiometric variability; however, females also demonstrated a significantly greater percentage of noise-exposed individuals. Thus, the small gender effect may have been influenced by TTS-related variability.

DISCUSSION

This investigation reveals pre-existing hearing loss to be a potentially significant confounding variable to ANSI S12.13 interpretations of HCP performance. Increasing (poorer) baseline hearing groups consistently demonstrated
Effects of Pre-existing Hearing Loss/Amos and Simpson

Figure 2 %Ws and %BWs outcomes as a function of baseline HTL group collapsed across gender and noise exposure categories.

ANSI S12.13 outcomes suggesting poorer HCP performance. The draft standard recommends that interpretations be based on agreements between two of the three (SDD, %Ws, and %BWs) protocols (ANSI, 1991). However, hearing level effects occurred with all three protocols.

It seems plausible that subjects with better hearing would likely yield greater audiometric variability results than those with poorer hearing. Fluctuant ambient background SPLs permissible by 29 CFR 1910.95 and biological noises have greater likelihood of interfering with the test signal for subjects with better HTLs, potentially causing greater audiometric variability. Royster and Royster (1990) reported that an HCP must adequately control audiometric testing factors and prevent TTS to achieve acceptable variability in the database.

Both laboratory and field data would tend to support an assumption of greater test–retest variability for more sensitive ears (Taylor et al, 1969; Melnick, 1978).

Invariant high ambient noise levels, however, may have caused a “floor effect” in variability outcomes. It is well understood that ambient background noise levels permissible by federal regulations likely preclude reliable assessment of auditory sensitivity near audiometric zero (OSHA, 1983; Franks et al, 1992). Even in the absence of invariant high background noise, many industrial audiometers do not go below audiometric zero, further predisposing threshold variability outcomes for sensitive ears to a “floor effect.” Mean hearing shifts in Table 1 provide some support for this notion. Better hearing level groups consistently demonstrated hearing declines, while poorer hearing level groups consistently exhibited hearing level “improvements.” Also, data reported by Chen and Pell (1989) are consistent with this investigation and may provide additional support for potential of a floor effect. Furthermore, data reported by Robinson (1991) may provide indirect support for the hearing level effect observed in this investigation.

Subjects with poorer HTLs may have demonstrated less attention and cooperation during audiometric testing. Gelfand (1981) reported that manual and computer-implemented audiometric testing methods are subject to a variety of response bias effects that reflect subject willingness to respond rather than the underlying sensory capability. Subjects aware of hearing loss may have been less motivated to respond reliably. As well, Chung et al (1984) reported exponential increases of tinnitus prevalence with
increasing hearing level in an industrial population. It is highly likely that tinnitus may have contributed to increased variability in poorer hearing level groups.

The modest gender effect noted in this investigation is considered to be equivocal. Females demonstrated slightly more audiometric variability than males. Slightly better mean hearing levels in female groupings is suggestive that a gender effect may exist for ANSI S12.13 outcomes. That is, based upon hearing sensitivity comparisons to males in this study, females might be expected to exhibit less threshold variability. On the other hand, slightly greater percentages of noise-exposed females may have biased outcomes towards greater TTS-related threshold variability.

Implications for HCP Managers

If hearing level effects demonstrated in this investigation are shown to be consistent in other industrial populations, caution is warranted by HCP managers when applying ANSI S12.13 protocols to populations differing in HTL characteristics from the ANSI sample underpinning published HCP performance ratings. It may be prudent for HCP managers to calculate ANSI variability outcomes for subsets of audiometric data with different baseline hearing level characteristics. Particular care may be warranted when comparing relative audiometric variability between two HCPs differing markedly in hearing sensitivity. It may also be prudent for the ANSI working group to reinvestigate published data samples for potential biasing effects of hearing level on threshold variability outcomes.

Data from this investigation indicate that poorer hearing populations may consistently yield ANSI outcomes suggesting need for improved hearing protection, particularly in cases where poor audiometric testing practices have been ruled out as contributing to unacceptable levels of threshold variability. In these cases, TTS would be implicated, and resulting safety decisions may lead to overzealous attenuation of hearing-impaired populations, placing them at risk of inability to hear critical communication or warning signals. Furthermore, ANSI S12.13 outcomes may overestimate HCP performance for better hearing populations (i.e., many new hires) by yielding overly optimistic interpretations of hearing protector performance, leaving them at risk for unnecessary hearing loss. Additional data will be necessary, however, to confirm these assumptions.

Although this investigation fails to rule out the possibility of gender effects on ANSI S12.13 outcomes, less caution appears to be warranted by HCP managers when interpreting outcomes differing in gender make-up.

Limitations and Research Needs

This study should be considered to be a preliminary investigation. There are several important limitations to this investigation:

1. Only serial audiograms 1 and 2 were considered in this investigation. Segregating baseline audiograms by hearing level may have thrown a disproportionate number of invalid baselines into poorer hearing groups, which may have biased these groups towards greater threshold shift variability from test 1 to test 2. A follow-up study is planned to identify potential hearing level effects for later sequential test comparisons (i.e., tests 3-4, 4-5, 7-8, etc.) to see if initial hearing loss affects later ANSI outcomes. Percent better-or-worse sequential outcomes are considered valid only for sequential test 5-6 comparisons or greater.

2. Population age was not considered in this investigation. Decreasing hearing as a function of age has been well documented (Gorig and Davis, 1961; Corso, 1963; Berger et al, 1977). Table 1 indicates, as expected, mean age increased from HTL group 1 to 2 to 3 for females and males. Age effects on ANSI S12.13 outcomes, however, are not reported in the draft standard. Because there was no control for age in this investigation, a potential age effect may have confounded results of this study. Future investigations could address this issue by oversampling poorer hearing young employees and better hearing older employees (Gatehouse and Davis, 1992).

3. Similar findings in larger sample sizes with heterogeneous occupational exposures will be necessary to rule out noise exposure and hearing protector use as potentially confounding factors in this investigation. In particular, hearing level effects should be investigated in high-noise populations suspected of insufficient hearing protector use to identify potentially confounding hearing level effects on the ability of ANSI S12.13 outcomes to identify TTS.

It is implausible that these stated weaknesses could be adequately addressed using the same
database in future research. Utilization of larger sample sizes from demographically diverse HCPs will be necessary to confirm these findings. Furthermore, investigation of a longitudinal sample may be warranted.

CONCLUSIONS

This study was a preliminary investigation of the extent to which pre-existing hearing loss and gender may affect proposed ANSI S12.13 (1991) audiometric variability outcomes for evaluating HCP effectiveness. Results of this investigation led to these general conclusions:

1. This study revealed a marked baseline hearing level effect in ANSI S12.13 outcomes. Poorer pre-existing hearing status resulted in greater audiometric variability. This result was likely not confounded by differing occupational noise exposures across baseline hearing level groups. HCP managers should carefully consider pre-existing hearing loss when using ANSI protocols to assess relative program effectiveness.

2. Although a modest gender effect of greater female audiometric variability was noted for ANSI S12.13 outcomes, this result may have been confounded by occupational noise exposure differences across gender categories. Some caution may be warranted when interpreting relative ANSI S12.13 outcomes from populations with differences in gender composition.

3. Future research should further examine the effects of baseline hearing level and gender on ANSI S12.13 outcomes beyond test 1 and test 2 comparisons. This research should employ larger sample sizes to more adequately account for demographic and noise exposure differences between HCPs.

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REFERENCES


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