▶ *OCCUPATIONAL HEARING CONSERVATION*

How Can We Evaluate the Effectiveness of Occupational Hearing Conservation Programs?

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To prevent *noise-induced hearing loss* (NIHL) at work, occupational *hearing conservation programs* (HCPs) have been required by the U.S. Department of Labor since 1971[1], with audiometric monitoring required by the Occupational Safety and Health Administration (OSHA) since 1983.[2] Most industrial workers are covered by these HCPs (with agricultural workers being the most notable exception, and employees in construction and mining partially covered under other regulations).

Employees in OSHA-mandated HCPs theoretically are educated about noise-induced hearing loss and its prevention, individually fitted with hearing protection devices which offer appropriate attenuation for their noise exposures, and both taught and supervised to wear the devices correctly and consistently. Annual audiometric monitoring audiograms are obtained and compared to baseline tests to identify those individuals whose hearing levels show beginning or progressive hearing loss. Ideally, workers are warned about beginning hearing changes. If the change from baseline accumulates enough to show an OSHA standard threshold shift (usually after application of optional age corrections), then OSHA requires that the audiometric record be reviewed by a professional, the employee informed of the shift and the individual's hearing protector selection re-evaluated, with user refitting and retraining carried out. OSHA requirements outline the minimum legally acceptable HCP. However, if these steps are implemented in a mediocre fashion, as is often the case, then noise-induced hearing loss will *not* be prevented. Therefore, regular evaluations are needed to determine whether employees are actually being protected from noise, whether the employer's investment of time and money is delivering the intended benefit and whether improvements are needed to make the HCP more effective.

> Although noise-induced hearing loss (NIHL) is preventable (excluding accidental acoustic trauma), it accounts for more hearing loss than any other cause except presbycusis. Inadequately protected noise exposure can cause hearing damage, either on or off the job, but most individuals receive the majority of their hazardous noise exposure in the workplace, rather than in home or recreational settings.

Audit Approaches

In an audit, the evaluator tallies whether the HCP is complete by checking whether each required element is present and in compliance with regulations (or ideally with more stringent requirements imposed by the employer). The challenge of the audit approach is in judging the quality of the elements which are present, since half-heartedly "going through the motions" typically yields no benefit at all except adherence to the letter of the law (that is, avoidance of OSHA citations). Checklists are available[3,4] for use in audits, but the results depend on the auditor's expertise and on the level of detail of the auditor's examination of HCP procedures. In the authors' experience, internal company audits often fail to detect omissions or errors, which are simply perpetuated.

Annual performance statistics are another audit approach to HCP evaluation. Relevant data may include the percent of personnel wearing HPDs on the shop floor in random checks, the percent of employees who can demonstrate


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correct HPD insertion upon request, the percent of audiograms administered on time, the percent of retests achieved within 30 days, etc. Longer-term measures of success include the numbers of employees removed from the HCP after implementation of engineering noise controls, or reductions in the typical noise exposure values for various departments. (Of course, increases in such numbers would be undesirable indications of an expanding HCP with a growing noise hazard.)

STS Rates

The statistic most commonly interpreted as an indicator of HCP performance is the annual rate of confirmed OSHA *standard threshold shift* (STS), which is a change of 10 dB or more from baseline values in the average of hearing thresholds at 2000, 3000 and 4000 Hz (usually after application of optional age corrections). Employers often believe that if current STS rates are low, then their HCP is successful. However, characteristics of the development and progression of NIHL invalidate this assumption.[5] Because STS averages three test frequencies which are differentially susceptible to *noise-induced permanent threshold shift* (NIPTS), persons with initially good hearing will develop large high-frequency shifts before the average changes by 10 dB (especially after age corrections). Conversely, persons who already exhibit significant high-frequency hearing loss on their baselines will be less likely to develop STS; and if they do, then the shift will often result from larger changes at 2000 Hz than at higher test frequencies. Most workplace environments do not have noise exposures high enough to cause more than one STS in a working lifetime, even with no protection from a HCP.[6]

Factors which affect the rates of new age-corrected STSs[7,8] include:

▶ *Employee turnover:* STS rates are reduced if turnover is high, and increased if turnover is low.

▶ *Age of workforce*: STS rates are increased if there are many older employees, especially those with high seniority. Median age corrections are insufficient to adjust out greater-than-median aging trends for many workers, who therefore will develop STS even without noise exposure. (Of course, the flip side is that median corrections over-correct for the opposite tail of the distribution—those persons who develop less age-effect loss than expected.) In addition, OSHA age-corrections stop at age 60 years, when presbycusis is accelerating.

▶ *Pre-existing hearing loss on baseline audiograms*: STS rates are reduced if baselines already reflect high-frequency hearing loss.

▶ *Calibration or methodological changes*: STS rates may either increase or decrease if baselines and later tests exhibit a systematic difference related to testing instrumentation and/or methods.

▶ *Prior STSs*: After many employees have shown one STS, subsequent rates of new STSs will be reduced since few individuals will ever show a second STS.

The factors mentioned above make STS unsuitable as an indicator of HCP effectiveness. Very high STS rates are clearly bad (though they are unlikely to be caused solely by NIPTS), but low rates do not necessarily reflect adequate protection of employees. If the factors above are accounted for, then relative differences in STS rates among departments within a plant may be informative, but STS is never the most sensitive indicator of HCP problems.

Audiometric Data Base Analysis (ADBA)

ADBA is a performance-based approach to HCP evaluation using population hearing levels as the gold standard and yielding information not obtainable through compliance-oriented audits or STS rates. The HCP is judged as acceptable if the noise-exposed population does not exhibit significant development or progression of occupational NIHL and if there is low variability in year-to-year audiometric threshold measurements.

▶ *Absolute Hearing Level Values:* One ADBA approach involves comparisons of the hearing levels (HLs) of noise-exposed populations to those of control groups; the measured HLs of groups of exposed employees are compared to the expected age-related HLs for their matching age, gender and race using Annex C of ANSI S3.44-1996.[5] This approach yields a historical snapshot: at a single point in time, after a defined duration in the HCP, the noise-exposed employee population shows HLs which hopefully are equivalent to the expected age-effect HLs (indicating perfect protection from noise). Comparisons at different points in time can demonstrate the improvement in HLs for groups exposed to noise after the initiation of the HCP.

For example, consider a HCP which began in 1981. Allowing several annual audiograms for the employees to become audiometrically experienced (yielding learning-effect improvement in measured HLs), the employees' median HLs in 1983 could be compared to reference expected age-effect HLs. In our example, let's assume that workers ages 35-45 with 10-20 years of service exhibited 4 kHz HLs that were 20 dB worse than expected, indicating the hearing loss suffered prior to the HCP's initiation. If a corresponding group in 1999 shows 4 kHz HLs only 5 dB worse than expected, then the HCP has afforded this population of workers substantial (though not perfect) protection in the intervening years.

Population comparison analyses of the type described above have been reported[9,10,11] and are one way of assessing the long-term success of HCPs on the basis of HL outcomes. However, this method is not proactive; it cannot give an advance warning that NIPTS is developing. To afford HCP personnel an early warning of deficiencies, other approaches are needed.

Note that it is essential that any procedure using audiometric data to evaluate HCPs consider each test frequency separately in each ear. Procedures which average across frequencies are insensitive to important trends because NIPTS affects different frequencies at different periods in its development and progression, and because artifacts (such as calibration deviations, audiometer malfunctions, masking by excess background noise, etc.) affect single frequencies. Averaging procedures are therefore unacceptable in evaluating HCP effectiveness.

▶ *Variability Indicators*: Draft ANSI S12.13-1991[12] provides simple analysis techniques which do yield an early warning of HCP problems. The rationale for these ADBA methods is that excess variability in audiometric thresholds from one year to the next indicates an ineffective HCP. Variability may be high for numerous reasons including: 1) inadequately protected noise exposure causing temporary and (eventually) permanent threshold shifts and 2) poorly controlled audiometric testing instrumentation, environment, methods and/or unreliable HL measurements. Although only the first reason results in NIPTS, the second cause of high variability also renders the HCP ineffective because the audiogram reviewer cannot react to apparent HL shifts with confidence. The point of monitoring audiometry is to provide follow-up to individuals who show hearing changes. If the entire population shows fluctuating HLs due to unreliable testing, then the reviewer cannot distinguish real shifts from spurious ones. Follow-up in this case may be counterproductive, since undeserved warnings may go to workers who actually have been fully cooperative in their HCP

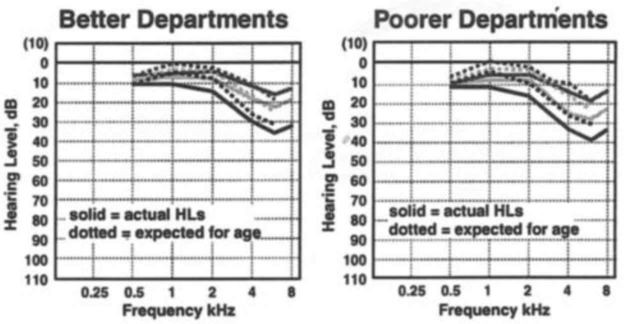

Fig. 1. *Expected median age-effect HLs from Annex C of ANSI S3.44-1996 (dotted lines: age 30 in dark gray, age 40 in light gray, age 50 in black) versus actual measured median HLs of noise-exposed employees (solid lines) in corresponding decade age ranges (26-35, 36-45, 46-55 years) for two groups of departments within a single company.*

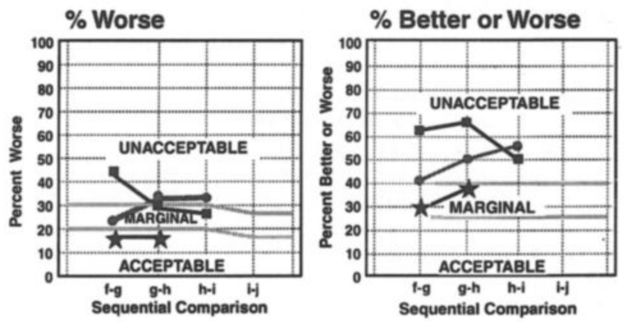

Fig. 3. *Draft ANSI S12.13-1991 variability results over the most recent available years of testing for three different companies sharing the same testing service.*

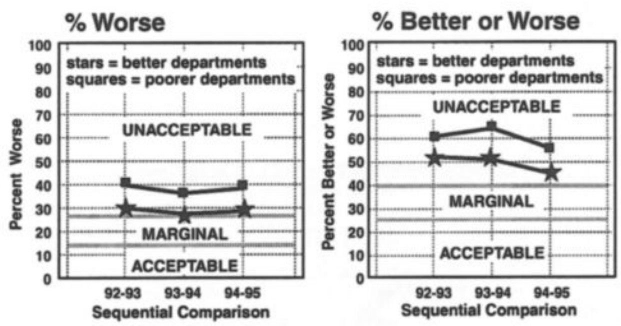

Fig. 2. *Draft ANSI S12.13-1991 variability results over the most recent four years of testing for two groups of departments within a single company.*

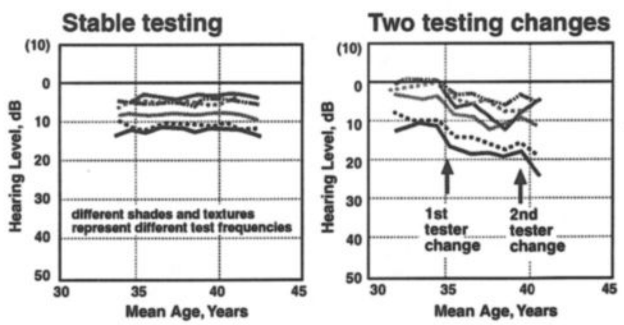

Fig. 4. *Mean HLs at .5, 1, 2, 3, 4, and 6 kHz over the latest ten annual audiograms for two groups of employees originally sharing the same test provider, but with two tester changes for the group shown in the right-hand panel.*

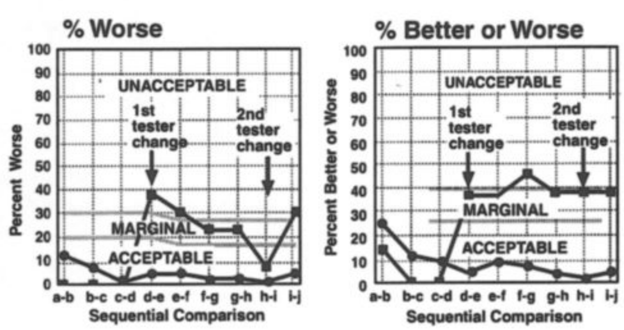

Fig. 5. *Draft ANSI S12.13-1991 variability results over the most recent ten years of testing for two groups of employees originally sharing the same test provider, but with two tester changes for the group whose data are plotted with square symbols.*

responsibilities (such as wearing HPDs faithfully).

Two simple procedures in Draft ANSI S12.13-1991 tabulate the extent of audiometric variability between sequential pairs of annual audiograms. By comparing each test to the preceding test (such as test 1 to test 2, 2 to 3, 5 to 6, etc.) rather than back to the baseline, the problems involved in age-corrections are avoided. Even more important, year-to-year changes in audiometric variability can be identified for a proactive early warning of problems. The two indicators which are tabulated are:

1) Percent Worse sequential ($\%W_S$): The percent of the population showing a change of 15 dB or more toward worse hearing at any frequency from 500-6000 Hz in either ear, and

2) Percent Better or Worse sequential ($\%BW_S$): The percent of the population showing a change of 15 dB or more either toward worse hearing or toward better hearing at any frequency from 500-6000 Hz in either ear.

On an annual basis the results obtained for these indicators are compared to criterion ranges of HCP performance derived from empirical study of real-world HCP data bases.[12] Different groups can be chosen for analysis, depending upon the evaluator's purpose: recent hires, long-term employees, low- versus high-noise-exposure groups, etc. If the variability is excessive, then the evaluator must determine why. Is it noise-related (indicating inadequate protection) or is it due to unreliable audiometry? An internal control group of non-noise-exposed subjects who receive annual audiograms provide a check of the audiometric reliability in the absence of noise exposure. Several examples will illustrate the use of these techniques.

In Example 1, absolute HLs corresponded fairly closely to age-norms for one group of departments within a company, but a second group of departments exhibited more apparent NIHL, as shown in Fig. 1. Variability statistics also demonstrated higher variability for the poorer departments, as shown in Fig. 2. Both testing-related factors and noise-exposure-related factors were implicated, since variability was undesirably high even for the better departments which showed no excess hearing loss beyond age-effect norms. However, HCP personnel determined that inconsistent HPD use among employees in the poorer departments accounted for their even higher variability results. The findings were used to support the need for establishing more accountability for HPD use in the affected departments. In addition, personnel investigated ways to reduce testing-related variability for the whole HCP.

Example 2 involves a company which split into two parts after many years with very stable audiometric monitoring performed in-house. One group continued with in-house testing, while the other group switched first to one mobile testing service, then to another. Absolute HLs shifted dramatically as a result of the testing changes, as shown in Fig. 3 (right panel). Variability also increased quite significantly, as shown in Fig. 4 (square symbols). These differences are due solely to audiometric factors, since employees' noise exposures remained the same.

Example 3 illustrates variability statistics over the most recent few audiograms for three different industries all tested by the same mobile service. Although the testing itself appears acceptable as judged by the marginal to good results shown in Fig. 5 for the industry graphed using star symbols, the other two industries showed higher variability. Since testing factors were the same for all three industries, the excess variability for the sites graphed using squares and diamonds is due to inadequate protection from noise in the responsible HCPs (inadequate HPD selection, fitting, and use; insufficient worker education and motivation, etc.).

These examples demonstrate that ADBA methods can identify excess audiometric variability due both to noise-exposure-related factors and to audiometric factors. The techniques can be applied to as few as two annual audiograms, allowing HCP personnel to get an annual update on HCP status plus an early warning if problems begin to appear. Additional examples and guidance are available in the literature.[13,14,15]

Conclusions

No HCP should go unevaluated. An on-going program evaluation process, including some form of objective data analysis, helps HCP team members keep their efforts focused on hearing loss prevention. Effective HCPs involve diverse activities by numerous personnel under the leadership of a motivated key individual, and it is easy for programs to become fragmented and ineffective if there is too little coordination and communication among the HCP team.[4] OSHA compliance in no way implies effectiveness. Careful audits may identify strengths and weaknesses, but the only gold standard is to use the information contained in the audiometric database.

Go beyond STS rates to evaluate HCP success using the hearing levels of the noise-exposed employees. Give Draft ANSI S12.13-1991 a try, and use the results to improve HCP performance. An effective HCP gives the employer a return on his/her investment, as well as giving employees better hearing for the rest of their lives! ◆

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