Review of Four New Indices of Susceptibility to Noise-induced Hearing Loss

Larry E. Humes, M.A.

Individual variances in susceptibility to acoustic trauma have been recognized for decades. Despite the apparent familiarity of this phenomenon, attempts to delineate “tough” from “tender” ears have met with little success. A major factor contributing to this failure has been the investigative technique most often employed, i.e., temporary threshold shift (TTS).

In 1933, Temkin formed the rationale underlying the TTS paradigm. He suggested that measurement of the auditory fatigue following a single moderate exposure to sound provided an accurate and simple estimate of the eventual permanent threshold shift (PTS). Attempts to confirm this hypothesis, however, have generally met with failure.

Recently, various investigators have recommended the use of different techniques in the assessment of susceptibility to inner ear damage from acoustic overstimulation. These techniques, discussed in greater detail below, are the aural overload test, the threshold of octave masking (TOM) test, brief-tone audiometry, and assessment of speech intelligibility in noise.

The Aural Overload Test

The aural overload test received its widest application in the late 1950’s and early 1960’s as a test of differential diagnosis. Carhart, in 1973, however, maintained that the true value of this technique lies in its sensitivity to preclinical cochlear pathology, i.e., susceptibility.

Aural overload is simply a distortion process that occurs within the inner ear at moderate stimulus intensities. Onset of overload can be determined either directly via electrophysiological measurements of the cochlear microphonic (CM) or indirectly through psychoacoustic methods. Traditionally, psychoacoustic estimation of aural overload has been employed with man while electrophysiological recordings are reserved for animal experimentation.

Lawrence and Blanchard were first to psychophysically evaluate susceptibility through the aural harmonic test. Prior to application of this test to man, these investigators electrophysiologically determined thresholds of aural overload in a number of guinea pigs. When these same animals were stimulated with intense sounds, a direct relationship was observed between the onset of overload and postexposure temporary threshold shift. That is, those animals exhibiting lower thresholds of distortion experienced greater TTS. This was true, however, only for fundamental frequencies above 700 Hz.

These investigators then proceeded to psychoacoustically measure aural harmonic thresholds in human ears. Lawrence and Blanchard found the range of thresholds to approximate that found in guinea pigs through more direct means. They concluded, therefore, that the aural harmonic test appeared to be sensitive to susceptibility differences among normal-hearing individuals.

It wasn’t until recently, however, that this hypothesis was put to direct test. Humes and Schwartz measured the auditory fatigue (TTS) for a 4000 Hz stimulus two minutes following exposure to 110 dB of white noise for a three-minute duration. Aural overload thresholds at 2000 Hz, measured prior to exposure, were inversely and linearly related to the amount of TTS (Temporary Threshold Shift at two minutes postexposure). That is, the lower the aural harmonic threshold, the greater the TTS. Figure 1 illustrates this relationship for the four subjects studied.

In a similar manner, Humes and Bess obtained preexposure
aural overload thresholds at 500, 1000, and 2000 Hz from five normal-hearing young adults. These individuals were then subjected to thermal noise at 110 dB sound pressure level for five minutes following which they traced threshold at 4000 Hz. The TTS at 4000 Hz was found to be highly correlated to mean aural overload threshold (average aural harmonic threshold at 500, 1000 and 2000 Hz). Further, the temporary threshold shift at 15 seconds postexposure, TTS, was also significantly (p < .05) correlated to the mean threshold of aural overload. Correlation coefficients (Pearson r) for TTS and TTS, with mean overload threshold were -.98 and -.84. Hence, as in the previous study, the lower the aural harmonic threshold, the greater the the TTS (Fig 2). This relationship was also borne out for the threshold of aural overload at 2000 Hz and TTS and TTS at 3000 Hz after stimulation with a 2000 Hz pure tone at 100 dB SPL for three minutes (r = -.87 and -.89, respectively).

Close scrutiny of the above data makes one thing strikingly apparent. Correlations for overload and TTS have never been obtained for low-frequency stimuli. As Humes and Schwartz note, however, the insensitivity of auditory threshold to low-frequency cochlear impairment may be the primary contributor to this poor correlation. Other investigators have commented similarly on the apparent insensitivity of TTS to cochlear damage in low-frequency regions.

**TOM Test**

The threshold of octave masking (TOM) test is similar to the aural harmonic test in that it provides an estimate of the onset of cochlear distortion. It developed as a consequence of the difficulty encountered on the part of the listener with the original aural overload procedure. Briefly, the TOM test estimates distortion onset by measuring the ability of an intense fundamental tone to mask extrinsically introduced tones that are equivalent to the aural harmonics in frequency.

Application of the TOM test to noise studies has occurred only recently. Cobb and Erdreich, for example, report (unpublished data) a distinct relation exists between the amount of TTS and thresholds of octave masking. Additionally, Humes and Clark (unpublished data) have applied this procedure to a group of normal-hearing (n = 10) and achieved correlations of -.76 (p < .01) for

**Fig 1.** Individual data points and calculated line of best fit describing the relationship between baseline aural overload threshold at 2000 Hz and the TTS at 4000 Hz following a 110 dB SPL exposure to broad-band noise. From Humes and Schwartz.

**Fig 2.** Prediction of TTS at 4000 Hz from mean aural overload threshold (□ = TTS and ◇ = TTS). Standard errors were 1.06 dB for the TTS regression line and 1.93 dB for the TTS regression line. From Humes and Bess.

TT at 4000 Hz and -51 (p < .06) for TTS. Temporal threshold shift was measured at 4000 Hz following five-minute exposures to broad-band noise at 110 dB sound pressure level.

The TOM procedure has a potentially broader application than the aural harmonic test because of the greater ease of the listening task. This has been found to be particularly evident for high-frequency stimuli.

**Brief-tone Audiometry**

A third potential measure of susceptibility, Brief-tone audiometry, involves the measurement of auditory threshold for pure tones for varying duration. In normal ears, as the tonal duration decreases, greater intensity is required to maintain audibility. With normal ears the trade-off of the time-intensity relationship is such that for a tenfold decrease in tonal duration (i.e., from 200 to 20 msec), an intensity increase of 10 dB is required to achieve threshold sensitivity. That is, the normal slope of temporal integration is 10 dB per tenfold decrease in duration.

Cochlear-impaired ears, including those damaged from excessive noise exposure, tend to exhibit a reduced slope of temporal integration. More importantly, Iger found that normal-hearing, during recovery from TTS, also display reduced slopes of integration. He reported further that the time-intensity relationship demonstrated gradual recovery over time. When this finding is viewed in light of the dependence of temporal integration on intact cochlear hair cells, one can reason that this recovery reflects the functional recovery of these sensory structures. Thus, brief-tone audiometry appears to be sensitive to alterations in inner ear sensory epithelium and consequently offers a possible index of individual proneness to noise-induced hearing loss. This hypothesis, however, awaits further investigation.

**Speech Discrimination Tests in Noise**

The fourth and final potential index of susceptibility to noise-
induced hearing loss to be discussed concerns the determination of word intelligibility scores assessed against a background of noise. This procedure involves the administration of a list of monosyllables at a suprathreshold level. Broad-band noise is mixed acoustically with the speech signal and presented monaurally at some level relative to the intensity of the speech signal. The difference in levels of the speech and noise is referred to as speech-to-noise ratio. If, for example, the monosyllables are presented at 70 dB SPL (approximately conversational speech level) and the noise at 60 dB, the speech-to-noise (S:N) ratio would be +10 dB.

Rupp and Phillips28 discovered that certain normal-hearers, possessing what they termed "normal fragile ears," scored very poorly on word intelligibility tests when administered in noise. They also found a high degree of internal consistency within subjects in that a subject performing poorly at one speech-to-noise ratio tended to breakdown substantially at all S:N ratios. Other investigators, however, have failed to confirm this latter finding.29 30

More recently, Humes, Bess, and Schwartz31 examined the breakdown of normal-hearers on intelligibility tests administered in noise at several S:N ratios. Aural overload thresholds were also obtained at 500, 1000, and 2000 Hz. For the most favorable signal-to-noise ratios a statistically significant correlation was obtained for low-frequency aural overload thresholds and speech discrimination scores in noise. Positive correlations were obtained suggesting that the lower the aural harmonic threshold, the lower the word discrimination score in noise. When the high correlation of aural overload to TTS is recalled, one can hypothesize that speech discrimination scores in noise offer another potential technique for assessing susceptibility. This possibility requires further investigation.

A possible direction for future studies is suggested by the findings of Olsen, Noffsinger, and Kurzdziel.27 These investigators obtained speech discrimination scores in quiet and in noise (S:N = 0 dB) for 150 normal ears. Rather than examining the score in noise alone, these researchers examined the amount of breakdown in noise, that is, how much their score was reduced in the presence of noise. For normal hearers, only 1% of the cases experienced a reduction in score of greater than 40%. Thus, the difference in score obtained in quiet and under noise may be more informative than the score in noise alone. Continued collection of normative data and the evaluation of various cut-off limits is necessary for the implementation of speech discrimination tests as measures of susceptibility.

Conclusion

The potential use of four new measures of susceptibility to acoustic trauma has been discussed. Each has the advantage, unlike TTS methodology, of not requiring a prior exposure stimulus. The use of an exposure sound has proven to be the major drawback to verification of Temkin's original hypothesis.3

A disadvantage inherent to the speech discrimination procedure involves the use of difficult-to-standardize speech materials and techniques. Consequently, one of the first three techniques, aural overload, threshold of octave masking, and brief-tone audiometry, is more desirable with aural overload having the most data to substantiate its use as a predictor of vulnerability to ear damage from acoustic overstimulation.

None of these tests, on the other hand, has been correlated to permanent threshold shift (PTS). This necessitates the use of experimental animals or the long-term monitoring of the hearing sensitivity of industrial workers. Such data should prove invaluable in the search for an effective predictor of eventual noise-induced hearing loss.

References
17. Humes LE and Bess FH: A test battery approach to the investigation of susceptibility to TTS. Audiology (in press).

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