

Auditory Tests for the Early Detection of Noise-Susceptible Individuals – A Literature Study

Joos Vos

TNO Human Factors
P.O. Box 23, 3769 ZG Soesterberg
The Netherlands

vos@tm.tno.nl

TESTS FOR THE DETECTION OF NOISE-SUSCEPTIBLE INDIVIDUALS

We reviewed the literature on the availability of auditory tests that determine, prior to being affected by significant hearing loss, to what extent an individual is susceptible to noise. The predictive power of tests that determine the acoustic reflex responsivity, and both temporal integration and non-linearities of the hearing system, may be large, whereas the predictability of tests that determine otoacoustic emissions and head related transfer functions seems to be small. The validity of the indices, however, can only be determined in longitudinal studies. To our knowledge, the results of such studies have never been reported.

1.0 INTRODUCTION

As a result of noisy military systems and the limited applicability of personal hearing protection, there continues to be a high incidence of noise-induced hearing loss (NIHL) among military personnel. One of the ways to reduce the adverse effects of noise, such as a decreased hearing acuity and a noticeable reduction in the ability to understand speech in noisy conditions, might be the selection of persons who are less susceptible to noise. The Netherlands Ministry of Defense contracted TNO Human Factors to investigate whether at present reliable auditory tests are available to determine in an early stage, i.e. prior to being affected by significant hearing losses, to what extent an individual is susceptible to noise.

2.0 DEGREE OF INDIVIDUAL DIFFERENCES

To give an idea of the degree in which the susceptibility to noise varies among individuals, Figure 1 reproduces median hearing thresholds of metal workers of the drop-forging industry and office and canteen personnel (control) reported in Taylor et al. [1], as a function of the frequency of the test tone. The metal workers had been exposed to A-weighted equivalent sound levels ($T = 8$ h) varying from 102 to 112 dB. With the help of vertical lines, the 90th (top) and 10th (bottom) percentiles are given as well. The data are shown for five separate groups with ages varying between 15 and 24 years up to between 55 and 64 years. The spread in the thresholds (difference between the thresholds for the 10th and the 90th percentiles) is also given in Table 1. Averaged across frequency, the spread increases from about 20 dB for the 15-24-year-old up to about 40 dB for the 35-44-year-old. For the two higher categories, the spread stabilizes at 45 dB, which must be an artifact caused by the employees with very high hearing losses who prematurely gave up their jobs. Averaged across the age groups the spread obtained for the lower frequencies of 0.5 and 1 kHz is about 15 dB smaller than that for the higher frequencies of 2 and 4 kHz. As references, Table 1 also shows the spread (10th - 90th percentiles) in the hearing thresholds for otologically normal persons that can be revealed from the data sets given in ISO 7029 [2]. The spread is averaged across males and

Vos, J. (2005) Auditory Tests for the Early Detection of Noise-Susceptible Individuals – A Literature Study. In *New Directions for Improving Audio Effectiveness* (pp. 5-1 – 5-6). Meeting Proceedings RTO-MP-HFM-123, Paper 5. Neuilly-sur-Seine, France: RTO.
Available from: <http://www.rto.nato.int/abstracts.aps>.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 01 APR 2005		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Auditory Tests for the Early Detection of Noise-Susceptible Individuals A Literature Study				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) TNO Human Factors P.O. Box 23, 3769 ZG Soesterberg The Netherlands				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001856, New Directions for Improving Audio Effectiveness (Nouvelles orientations pour l'amélioration des techniques audio)., The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

females. For persons older than 34 years, the spread in the thresholds for the highly exposed at frequencies of 0.5, 1, and 2 kHz is 10 to over 30 dB higher than that for the otologically normal persons.

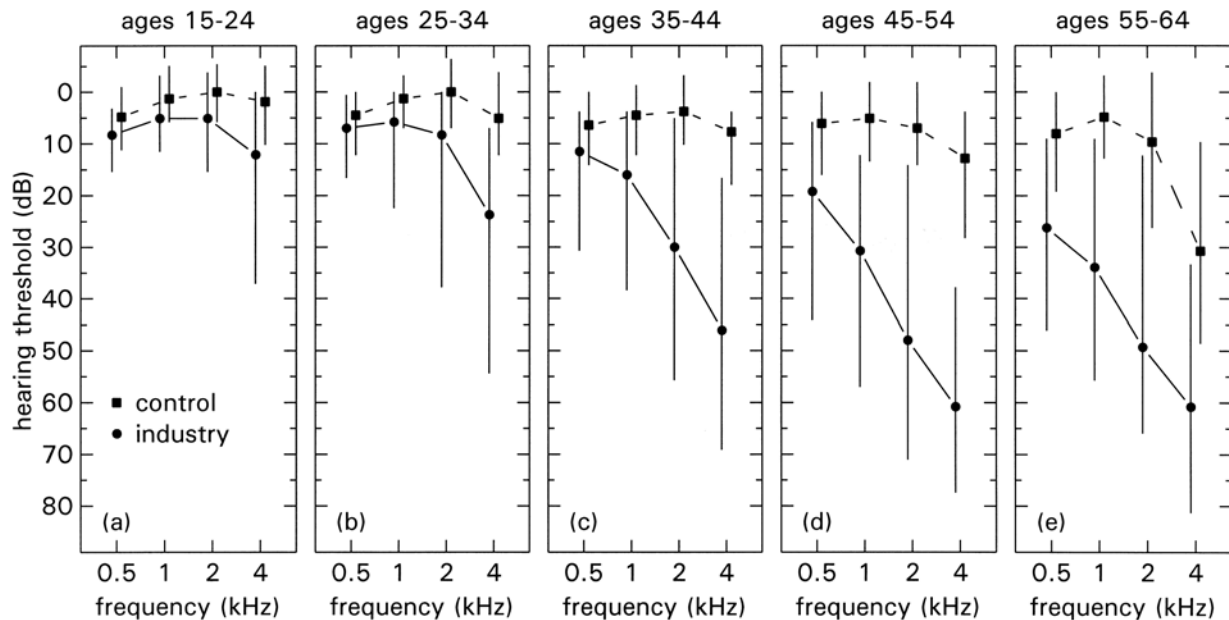


Figure 1: Median hearing thresholds of metal workers (industry) and a reference group (control) reported in Taylor et al. [1], as a function of the frequency of the test tone and for five separate age-groups. The top and bottom of the vertical lines represent the 90th and the 10th percentiles, respectively.

Table 1: Spread (in dB) in the hearing thresholds, expressed as the difference between the thresholds for the 10th and the 90th percentiles, for various frequencies and for workers in the drop-forging industry (DF) included in the study of Taylor et al. [1] and for otologically normal persons (ON) as described in ISO 7029 [2]. The difference between DF and ON is indicated by d; the mean (M) of these differences averaged across frequency or age is given in the last column and bottom row, respectively.

Age	500 Hz			1000 Hz			2000 Hz			4000 Hz			M
	DF	ON	d	DF	ON	d	DF	ON	d	DF	ON	d	
15-24	12	14	-2	15	14	1	19	16	3	37	19	18	5
25-34	16	15	1	22	15	7	38	17	21	47	20	27	14
35-44	27	16	11	35	16	19	51	20	31	53	25	28	22
45-54	38	18	20	45	18	27	57	23	34	40	32	8	22
55-64	37	21	16	47	21	26	54	28	26	48	41	7	19
M			9			16			23			18	16

3.0 AUDITORY TESTS

Changes in the hearing acuity that result from high sound exposures are often expressed as a temporary (TTS) or a permanent (PTS) shift in the hearing threshold. The effective individual sound exposure may be moderated by the acoustic reflex and anatomical properties of the ear canal and the concha. In addition, there are various psychoacoustical tests that provide insight in the way in which the hearing organ

integrates sounds in the time- and frequency domains. Since changes in these last features are observed earlier than changes as measured by means of the TTS and the PTS, much research focussed on the predictability of changes in especially the TTS from the results of tests that determine the integrating properties of the hearing system.

3.1 Acoustical Tests

Intense acoustic stimulation causes reflexive contraction of the middle-ear muscles. As long as the muscles are contracted, the transmission of sound energy is reduced. It is believed that the reduction protects the inner ear from intense sound. The literature is not quite consistent with respect to the relation between the magnitude of the *acoustic reflex* and the size of the TTS after sound exposure. Gerhardt and Hepler [3], for example, found a significant negative correlation between these two measures for tone bursts with a frequency of 1.4 kHz, but not for tone bursts with frequencies of 0.5 and 2 kHz. The interpretation about the cause-effect relationships is hampered by their observations that the magnitude of the acoustic reflex is reduced by the noise exposure itself. From a large-scale study on the relevance of various features of the acoustic reflex, comprising also measures such as the latency, rise and decay times of the reflex, Colletti and Sittoni [4] concluded that the stapedius reflex may play an important role in the protection against noise. In general however, it is felt that for a complete understanding of the cause-effect relationships, longitudinal studies are required.

As a result of individual differences in the shape of the ear canal entrance, the length of the ear canal, the cross-section area along the canal and the acoustic impedance of the tympani membrane, the *effectivity of the sound transmission* (HRTF) may differ from person to person. Hellström [5] determined the degree of TTS after exposure to noise for 36 subjects who were assigned to one of three groups depending on their mean sound transfer function for frequencies between about 3 and 6 kHz: low, middle, or high. The mean differences between the groups with a low and a high effectivity ranged between about 6 to 9 dB. The differences between the TTS as determined for either 2- or 4-kHz narrow-bandpass filtered white noise was about 5 dB at most. For the assessment of the practical relevance of these mainly anatomical differences, the test should be extended for lower frequencies of, for example, 250, 500 and 1000 Hz. Since for these lower frequencies the differences among the individual HRTFs are small, the overall effect on the TTS must be smaller as well. A related aspect, of course, is the shape of the concha and how far the ears project from the head. Ward [6] reported that there was a positive correlation between the TTS after exposure to noise and the magnitude of the ear projection.

Otoacoustic emissions (OAEs) are sounds in the ear canal that result from activity of the outer hair cells. When OAE is evoked by long series of pulse- or click trains, it is called a transient-evoked OAE (TEOAE). An OAE that occurs as a result of distortion is called a distortion product OAE (DPOAE). An OAE can also be produced spontaneously (SOAE), without deliberate sound stimulation. In several studies, the magnitude of TEOAE has been related to the hearing thresholds of groups of subjects with various degrees of hearing loss. By and large the results showed that for subjects with clearly measurable TEOAEs the hearing loss was generally small. Absence of TEOAEs, or a low reproduceability of specific components of them, however, were no reliable indicators of significant hearing losses: they could be found both in subjects with normal hearing and in subjects with deviating hearing thresholds (e.g., see Attias et al. [7]; Engdahl and Tambs [8]; Tognola et al. [9]). As a result, the TEOAE cannot be used in determining an individual's risk of hearing loss. This conclusion also holds for the DPOAE. The present author is unaware of reports about the relation between SOAE and hearing loss.

3.2 Psychoacoustical Tests

In various studies reported by Humes and colleagues (e.g., see Humes [10]; Humes and Bess [11]), the *threshold of distortion* is arbitrarily defined as the total sound level of two interfering tones at which the

beats are just no longer audible. For frequencies higher than 1 kHz, it has been found that the TTS decreases with increasing threshold of distortion. This threshold has never been related to PTS.

The *loudness discrimination* test proposed by Bienvenue et al. [12] determines the ability to detect small changes in the level of various sounds. People with a certain degree of noise induced hearing loss are able to detect smaller changes in sound level (loudness recruitment) than normal hearing subjects. Bienvenue et al. concluded that this discrimination test was an early and sensitive indicator of TTS. Without separate data on the TTS, however, this conclusion seems to be premature. In a study with naval aviators categorized as having either normal hearing or hearing threshold levels greater than 40 dB at frequencies between 4 and 8 kHz, Thomas and Williams [13] found that for frequencies of 2 and 4 kHz, the aviators with the hearing loss had deviating scores on a comparable discrimination task. Especially surprising was the result obtained for the frequency of 2 kHz: although the hearing threshold of the noise-susceptible subjects was still normal at this frequency, the result of the discrimination test already implicitly indicated the occurrence of loudness recruitment. This suggested that the test might serve as an “early warning” of noise-induced damage.

For short tone bursts the hearing threshold depends on both the frequency and the duration of the tones. For subjects with normal hearing, the trade-off between level and time is equal to –10 dB for a tenfold increase in tone duration. In a study reported by Lawton and Robinson [14] the mean slopes for a group of young and a group of older men were equal to –9.3 and –7.5 dB, respectively. For both groups the mean integration time was equal to about 150 ms. A portion of the variance in the hearing threshold at 4 kHz could be accounted for by the slope and the product of the slope and the logarithm of the integration time. For the younger and older groups the explained variance was equal to 28% and 60%, respectively. Lawton and Robinson [14] concluded that *brief-tone audiometry* might be a promising tool that should be included in future research on the detection of noise-susceptible subjects. The latter conclusion was confirmed in a subsequent study with soldiers who had experienced very heavy exposure to shooting noise whilst retaining substantially normal hearing sensitivity (Lawton and Robinson [15]).

The *threshold for octave masking* is a measure for cochlear distortion. Humes et al. [16] obtained a negative correlation between the masking threshold and the TTS: normal hearing subjects with a high threshold had a lower TTS. In the study reported by Lawton and Robinson [14] the slope of the masking threshold was significantly correlated with the hearing threshold level at 4 kHz. Especially for the group of older men the variance in the hearing thresholds accounted for by this slope was as large as 50%. After various analyses, Lawton and Robinson [15] concluded that resistance to hearing loss is associated with a steep slope of the octave masking threshold.

Bergman et al. [17] used the notched-noise procedure to determine changes in auditory *frequency selectivity* in noise-exposed industrial workers. The frequency selectivity was defined as the difference between the threshold of a test tone in broadband noise and the threshold of a test tone in noise with a spectral notch. A clear negative correlation between frequency selectivity and the hearing threshold level at 4 kHz was obtained. Since even for subjects with normal hearing there exists considerable variance in the frequency selectivity, this test might be a predictor for individual susceptibility to noise at the long term.

Speech reception thresholds and tone thresholds are clearly correlated. For the thresholds measured in 200 individuals with noise-induced hearing loss, Smoorenburg [18] found that the speech reception threshold in noise could be adequately predicted ($r = 0.72$) from the pure-tone average at 2 and 4 kHz. From the statistical association obtained in a typical cross-sectional study it cannot be inferred that hearing loss is a predictor for individual susceptibility to noise. Humes [10], however, referred to a study in which for the normal hearing subjects a significant positive correlation was found between the threshold of distortion and the discrimination scores for speech in noise at signal-to-noise ratios of 0 and 6 dB. Since a positive relation was found also between the threshold of distortion and the TTS, Humes’s hypothesis that speech reception might be a predictor for individual susceptibility to noise is plausible.

4.0 NONACOUSTIC FACTORS

The literature suggests that eye color is a predictor of individual susceptibility to noise: people with blue eyes might be more sensitive to noise than people with brown eyes (e.g., see Thomas and Williams [13]). A small effect of gender is reported also, with females being less sensitive than males. Nicotine intake might slightly enhance the prevalence of hearing loss (Henderson et al. [19]).

5.0 DISCUSSION

We reviewed the literature on indices of susceptibility to NIHL. In the literature various auditory tests are proposed that measure items such as loudness discrimination, octave masking, frequency selectivity, temporal integration, and the acoustic reflex responsivity. The main objective in the pertinent studies was to determine the correlation between the test results and the noise-induced TTS. Unfortunately, this approach has several weaknesses. Firstly, at present there are no convincing data showing that at an individual level, PTS can be predicted from TTS. Secondly, correlations between auditory test results and the TTS do not yield sufficient knowledge about real causal relationships. The difference in the effectivity of the sound transmission that results from anatomical differences among ears, is an example of a simple causal relationship. Especially the last ten years, much research has been devoted also to the relationship between various kinds of otoacoustic emissions and the hearing threshold. For subjects with measurable emissions, the hearing loss is generally small. Absence of emissions, however, is no reliable indicator of significant hearing losses.

We may conclude that the validity of the various indices of the individual susceptibility to NIHL can only be determined in longitudinal studies. In such studies, the promising auditory tests have to be administered to the participants at an early age before being affected by hearing losses. In our view the test battery should include acoustic reflex measurements, the determination of non-linearities of the hearing system (threshold of octave masking or threshold of distortion) and brief-tone audiometry. One might also consider including a test for speech reception in noise. The results obtained in the present literature study suggested that the measurement of otoacoustic emissions had a low priority. The disappointing results obtained in the cross-sectional studies, however, do not necessarily imply that individual changes in the otoacoustic emission observed in a lapse of many years cannot be used in the early detection of noise-susceptibility. This notion, and given that the measurement of otoacoustic emissions is neither time-consuming nor a burden to the subject, may justify inclusion of such a test also. After 10, 20, and possibly even after 30 years, the test results should then be related to the PTS that each participant may have suffered. In the literature, the need for such longitudinal studies has been frequently emphasized. To our knowledge, however, the results of such comprehensive studies have never been reported.

- [1] Taylor, W., Lempert, B., Pelmeier, P., Hemstock, I., & Kershaw, J. (1984). Noise levels and hearing thresholds in the drop forging industry. *J. Acoust. Soc. Am.* 76 (3), 807-819.
- [2] ISO 7029 (2000). Acoustics – Statistical distribution of hearing thresholds as a function of age. Geneva, Switzerland: International Organization for Standardization.
- [3] Gerhardt, K.J., & Hepler, E.L. (1983) Acoustic stapedius reflex activity and behavioral thresholds following exposure to noise. *J. Acoust. Soc. Am.* 74, 109-114.
- [4] Colletti, V., & Sittoni, V. (1986). Noise history, audiometric profile, and acoustic reflex responsivity. In *Basic and Applied Aspects of Noise-Induced Hearing Loss* (eds. R.J. Salvi, D. Henderson, R.P. Hamernik, and V. Colletti) Series A: Life Sciences, Vol. III (New York: Plenum Press), pp. 247-269.

- [5] Hellström, P.-A. (1993). The relationship between sound transfer functions from free sound field to the eardrum and temporary threshold shift. *J. Acoust. Soc. Am.* 94 (3), Pt. 1, 1301-1306.
- [6] Ward, W. D. (1965). The concept of susceptibility to hearing loss. *J. Occup. Med.* 7 (12), 595-607.
- [7] Attias, J., Furst, M., Furman, V., Reshef, I., Horowitz, G., & Bresloff, I. (1995). Noise-induced otoacoustic emission loss with or without hearing loss. *Ear & Hearing* 16 (6), 612-618.
- [8] Engdahl, B., & Tambs, K. (2002). Otoacoustic emissions in the general adult population of Nord-Trøndelag, Norway: II. Effects of noise, head injuries, and ear infections. *International Journal of Audiology* 41, 78-87.
- [9] Tognola, G., Grandori, F., Avan, P., Ravazzani, P., & Bonfils, P. (1999). Frequency-specific information from click evoked otoacoustic emissions in noise-induced hearing loss. *Audiology* 38, 243-250.
- [10] Humes, L.E. (1977). Review of four new indices of susceptibility to noise-induced hearing loss. *J. Occupational Medicine* 19 (2), 116-118.
- [11] Humes, L.E., & Bess, F.H. (1978). A test battery approach to the investigation of susceptibility to temporary threshold shift. *Acta Otolaryngology* 86, 385-393.
- [12] Bienvenue, G.R., Violon-Singer, J.R., & Michael P.L. (1977). Loudness discrimination index (LDI): a test for the early detection of noise-susceptible individuals. *Am. Ind. Hygiene Assoc. J.* 38, 333-337.
- [13] Thomas, G.B., & Williams, C.E. (1988). Noise susceptibility: a comparison of two naval aviator populations. In *Proceedings Noise as a Public Health Problem*, Vol. 2, 195-201.
- [14] Lawton, B.W., & Robinson, D.W. (1986). An investigation of tests of susceptibility to noise-induced hearing loss. (ISVR, Southampton, UK) ISVR Contract Report No. 86/8.
- [15] Lawton, B.W., & Robinson, D.W. (1987). Further investigation of tests for susceptibility to noise-induced hearing loss. (ISVR, Southampton, UK) ISVR Technical Report No. 149.
- [16] Humes, L.E., Schwartz, D.M., & Bess, F.H. (1977). The threshold of octave masking (TOM) test as a predictor of susceptibility to noise-induced hearing loss. *J. Auditory Research* 17, 5-12.
- [17] Bergman, M., Najenson, T., Korn, C., Harel, N., Erenthal, P., & Sachartov, E. (1992). Frequency selectivity as a potential measure of noise damage susceptibility. *British Journal of Audiology* 26, 15-22.
- [18] Smoorenburg, G.F. (1992). Speech reception in quiet and in noisy conditions by individuals with noise-induced hearing loss in relation to their tone audiogram. *J. Acoust. Soc. Am.* 91 (1), 421-437.
- [19] Henderson, D., Subramaniam, M., & Boettcher, F.A. (1993). Individual susceptibility to noise-induced hearing loss: an old topic revisited. *Ear & Hearing* 14 (3), 152-168.