ASSESSMENT OF OCCUPATIONAL HEARING REQUIREMENTS

Stanley Forshaw
3958 Sherwood Road
Victoria, B.C. V8N 4E6

Kevin Hamilton
Ergonomics and Human Factors Group
B.C. Research Inc.
3650 Westbrook Mall
Vancouver, B.C. V6S 2L2

ABSTRACT

The Canadian Coast Guard is presently reviewing its medical standards and, in particular the physical requirements that are essential for safe and effective marine operations. Typically, hearing standards used by many defence and transportation organizations are based on pure-tone thresholds and do not address the suprathreshold requirements of an individual's duties or work environment. This paper summarizes the research that has been directed towards identifying the onset of hearing handicap and examines current standards in the light of this research. Recommendations are made concerning the procedures that should be employed in setting occupational hearing standards.

SOMMAIRE

La Garde Cotière Canadienne revise présentement les standards médicaux, en particulier les exigences physiques qui sont essentielles pour la sécurité et l'efficacité des opérations maritimes. Typiquement, les standards auditifs utilisés par les différentes organisations de défense et de transport sont basés sur les seuils des sons purs et ne considèrent pas les exigences de supraseuil des fonctions d'un individu ou de l'environnement de travail. Cet article résume la recherche qui porte sur le seuil d'apparition du handicap auditif et examine les normes actuelles reliées á cette recherche. Des recommandations sont faites concernant les procédures qui devraient être employées lors de l'établissement de normes auditives au travail.

1. INTRODUCTION

Hearing impairment[1] in everyday activities can have many consequences. At the individual level it may hinder speech communication and social interaction. It may also have an economic impact by restricting employment opportunities and affecting job performance and safety.

The effect of hearing impairment on job performance is of particular concern when voice communication is an essential duty. In the aviation and marine environments, for example, speech is used frequently when messages are short and interactive and must be conveyed quickly. It is critical that what needs to be heard and understood is heard and understood.

Depending on the severity of an individual's impairment and the degradation of the speech signal due to poor-acoustic or sound-transmission conditions, messages received by the individual may be perceived correctly in total or in part, or may be misunderstood entirely.

As a result, it has been necessary for responsible jurisdictions to adopt appropriate hearing standards as a condition of employment where hearing ability may have an impact on operational effectiveness and safety. Currently, the Canadian Coast Guard (CCG) is reviewing its medical standards to define the critical components of medical fitness, including hearing, that are essential for safe and efficient operations. This paper summarizes the major findings of a review of the scientific literature on hearing standards and clinical procedures that pertain to the assessment of hearing handicap in support of the ongoing CCG medical review program.

2. CLINICAL HEARING TESTS

Hearing threshold, or hearing level (HL), is measured with reference to the mean hearing sensitivity of young adults with no hazardous occupational-noise exposure or known hearing

1. "Impairment" denotes a pathological condition that affects an individual's abilities, compared to non-impaired or normal abilities. "Disability" is related to actual or presumed reduction in ability to remain employed at full wages. "Handicap" describes the disadvantage in everyday circumstances resulting from a disability or impairment (WHO, 1980). The clinical manifestation of hearing impairment is the beginning point for evaluating auditory handicap and disability.

impairment. Hence, 0 dB HL at a given frequency is the sound pressure level (SPL) of the pure-tone stimulus that can just be detected on average by young normal-hearing adults. Persons who are able to hear pure tones below 15 dB HL across a range of frequencies (250, 500, 1000, 2000, 3000, 4000, 8000 Hz) are considered to have normal hearing. Hearing losses in excess of 15 dB may appear at one frequency, a group of frequencies, or the entire range. When HLs average 25 dB across the frequency range from 500 to 2000 Hz, difficulties begin to be encountered in hearing everyday sounds in everyday conditions. At 30 dB HL, most individuals are aware of their hearing deficit. When their deficit reaches 40 to 65 dB HL, those affected have difficulty hearing conversation at distances beyond about 2 metres (Anon, 1994).

Although HLs are important for quantifying hearing loss, they offer no direct information about a possible handicap in terms of the ability to understand speech in social and occupational environments. Hence, hearing loss should also be evaluated primarily in terms of speech-perception impairment. This is accomplished in two ways. The first is by determining the threshold of hearing for speech, termed the speech reception threshold (SRT). It is the hearing level at which 50 per cent of two-syllable words are heard correctly. The second procedure is a discrimination test, in which monosyllabic words or simple sentences are presented approximately 40 dB above an individual's SRT, and is scored as per cent correct. Since hearing handicap is first perceived when listening to speech in noisy conditions, discrimination ability is often measured in a background of noise at a number of speech-to-noise (S/N) ratios.

3. PREDICTING THE ONSET OF HEARING HANDICAP

The exact level of the onset of hearing handicap, termed the 'low fence', has been the subject of much debate. A fence that is set too high would result in persons with a handicap being ineligible for disability compensation, and workers in noisy environments being denied regulatory protection. Furthermore, persons performing critical communication tasks might not be able to perceive speech adequately (Suter, 1989). If the fence is set too low, individuals would be compensated even though their hearing losses resulted entirely or in part from presbycusis (hearing loss due to aging). Regulations would be unnecessarily stringent and expensive, and workers would be disqualified from jobs which they could perform satisfactorily.

Early procedures for estimating hearing handicap were based on pure-tone thresholds, typically the three-frequency average of HLs at 500, 1000 and 2000 Hz (AAOO, 1959). Subsequent research data for impaired speech perception in noise led to the inclusion of the HL at 3000 Hz in the average with the low fence set at 25 dB (AAO, 1979). The British Association of Otolaryngologists and the British Society of Audiology recommended a low fence of 20 dB for the mean HLs at 1000, 2000 and 4000 Hz (BAOL/BSA, 1983).

Acton (1970) and Suter (1978, 1985) attempted to pinpoint the HL at which persons with mild hearing losses begin to lose speech perception. They estimated that hearing handicap begins at an average HL of 19 dB at 1000, 2000 and 3000 Hz. This value translates to approximately 9 dB at 500, 1000 and 2000 Hz, and 22 dB at 1000, 2000 and 4000 Hz, since most individuals with mild sensorineural impairments[2] have threshold profiles that slope toward the high frequencies. Suter noted that the selection of a fence depends on the definition of hearing handicap and the conditions under which the handicap is assessed. Smoorenburg also studied the question of the low fence. He defined the onset of hearing handicap as the point at which an individual begins to notice a handicap in somewhat noisy everyday situations (Smoorenburg, 1986, 1992). He identified this point as an average HL of 30 dB at 2000 and 4000 Hz.

In an extensive investigation of speech-perception handicap, Robinson *et al* (1984) tested normal-hearing and hearing-impaired subjects in a variety of listening tasks. The tasks covered a number of situations including a simulated social gathering, a set of public address announcements recorded at the Waterloo Railway Station, and a telephone listening situation involving speech and noise. The listeners were also tested for speech discrimination with CVC (consonant-vowel-consonant) monosyllables at several S/Ns.

The results showed large differences between the two groups of subjects. There were also large differences within the groups and even within the same subjects' responses across tests. The mean HL at 3000, 4000 and 6000 Hz correlated most highly with performance on the three simulations, and the mean HL at 1000, 2000 and 3000 Hz correlated best with the speech discrimination tests. It was concluded that a threshold of handicap could not be identified because the threshold is dependent on the difficulty of the test. Hence, the selection of any one set of conditions for the definition of 'beginning-of-handicap' is necessarily arbitrary. Since their threshold data were in the range 27 to 34 dB HL, averaged over the frequencies at 1000, 2000 and 3000 Hz, they decided on a low fence of 30 dB at these three frequencies.

4. CURRENT HEARING-PERFORMANCE CRITERIA

Notwithstanding the uncertainty associated with specifying a threshold of handicap, the general consensus of the research cited herein points to a low fence between 19 dB at 1000, 2000

2. Pathologies that involve the inner ear (cochlea) and/or the neural pathways between the cochlea and the auditory cortex are termed sensorineural. Pathologies of the external or middle ear that interfere with the conduction of sound pressure variations to the inner ear are termed conductive.

and 3000 or 4000 Hz; and 30 dB at 1000, 2000 and 3000 Hz, or at 2000 and 4000 Hz (see Table 1). In the light of this, the hearing standards of a number of defence and transportation jurisdictions are summarized as follows.

4.1 Health and Welfare Canada (H&W)

The Occupational Health Assessment Guide, issued by the Occupational and Environmental Health Services Directorate of H&W Canada (Anon, 1994), prescribes minimum standards for pre-placement and periodic medical examinations of civilians. The Class 1 Hearing Standard requires average HLs not greater than 25 dB in the better ear and 30 dB in the poorer ear in the frequency range 500-3000 Hz (Table 2). The standard may be met with a hearing aid.

4.2 Canadian Forces (CF)

The CF uses Hearing Categories for the initial assignment of personnel to its various military occupations. Hearing Category H1 requires HLs not greater than 25 dB in both ears in the frequency range 500-8000 Hz (Table 3). H1 Category is generally required for air-crew selection. An experienced officer or trades-specialist who experiences a reduction in Hearing Category is considered for retention in his/her occupation on individual merit by a Career Medical Review Board (CMRB). Although not stated, the CMRB relies in part on the results of a full audiometric assessment including speech reception and discrimination testing when reviewing hearing-loss referrals.

TABLE 1.
ESTIMATES OF THE ONSET OF HEARING HANDICAP IN TERMS OF HEARING LEVELS AVERAGED OVER A RANGE OF FREQUENCIES

ONSET OF HANDICAP	FREQUENCY RANGE	SOURCE
19 dB HL	1000, 2000, 3000 Hz	Acton (1970), Suter (1978, 1985)
25 dB HL	500, 1000, 2000, 3000 Hz	AAO (1979)
20 dB HL	1000, 2000, 4000 Hz	BAOL/BSA (1983)
27-34 dB HL	1000, 2000, 3000 Hz	Robinson *et al* (1984)
30 dB HL	2000, 4000 Hz	Smoorenburg (1992

TABLE 2.
HEALTH AND WELFARE CANADA HEARING CLASSIFICATIONS

STANDARD	AVERAGE HEARING LEVEL IN BETTER EAR	AVERAGE HEARING LEVEL IN POORER EAR	FREQUENCY RANGE
Class 1	No more than 25 dB HL	No more than 30 dB HL	500-3000 Hz
Class 2	No more than 25 dB HL		500-3000 Hz
Class 3	No more than 30 dB HL		500-3000 Hz
Class 4	No more than 30 dB HL		500-2000 Hz

The above H&W Classes apply with or without hearing aids.

TABLE 3.
CANADIAN FORCES HEARING CATEGORIES (1995)
(A-MD-154-000/FP-000)

CATEGORY	HEARING LEVEL	FREQUENCY RANGE
H1	Not to exceed 25 dB in each ear.	500-8000 Hz
H2	Not to exceed 25 dB in each ear.	500-3000 Hz
H3	Not to exceed 50 dB in either ear.	500-3000 Hz
H4	Not to exceed 50 dB in either ear which cannot be improved to a higher Category with surgery or the use of a hearing aid.	500-3000 Hz

Category H2 is the maximum assigned for hearing assisted by hearing-aid amplification.

4.3 Canada Transportation Commission - Railway Act

The Canadian Railway Act (Anon, 1985) states that individuals employed by a Canadian railway company in specified occupations must not have hearing less than 20/20 when tested by means of the human voice, or a HL not greater than 20 dB at 500, 1000 and 2000 Hz. Where an individual is able to hear in each ear and repeat an ordinary conversation or names and numbers spoken in a conversational tone by an examiner at a distance of 20 feet, the hearing of the individual is expressed by the fraction 20/20. If the greatest distance at which the conversational voice can be heard is 10 feet, the fraction is 10/20. No railway company can retain in the specified occupations, an individual who has hearing less than 15/20 in the better ear and 5/20 in the poorer ear, or 10/20 in each ear, or has HLs of 40 dB or greater at 500, 1000 and 2000 Hz. Waivers can be obtained for assignments in which the hearing loss does not prevent the proper and safe performance of the assignments.

4.4 U.S. Air Force Hearing Threshold Profiles (AR 40-501, 1987)

The U.S.A.F. Hearing Profile H1 specifies that at 500, 1000 and 2000 Hz, HLs must not exceed 25 dB in each ear. At 3000, 4000 and 6000 Hz, the sum of the HLs at these frequencies for both ears must not exceed 270 dB. Occupations or activities requiring the H1 Profile include Flying Classes I and IA, initial selection for Air Traffic Controller Duty, initial selection for Missile Launch Crew, and Air Force Academy Admission.

4.5 U.S. Army Hearing Threshold Standards for Aviators and Applicant Aviators

The U.S. Army has drafted revised Hearing Threshold Standards for flight personnel (Mason, 1995). Applicant aviators may not have HLs exceeding 25 dB at 500, 1000 and 2000 Hz, 35 dB at 3000 Hz, 55 dB at 4000 Hz, and 65 dB at 6000 Hz. Trained personnel who do not meet this standard are referred for a complete audiological evaluation including binaural speech reception and discrimination testing. They are not returned to flying duties if their binaural speech discrimination is less than 84 per cent and/or the individual subjectively feels unsafe while flying due to hearing loss..

4.6 U.S. Army Hearing Profiles for Non-Flying Personnel (AR 40-501, 1987)

The U.S. Army Non-Flying H1 Hearing Profile requires HLs not greater than 25 dB at 500, 1000 and 2000 Hz and not greater than 45 dB at 4000 Hz. Officers initially assigned to the Armour, Artillery, and Infantry branches, as well as to the Corps of Engineers, Military Intelligence, Military Police Corps, and Signal Corps must meet the H1 profile. If an individual's hearing deteriorates, the individual may still be retained if he or she can demonstrate a continuing ability to perform the required duties or is able to perform these duties with the help of a hearing aid. In occupational specialties where communication and signal detection are particularly important, the Army lists hearing requirements in addition to the H1 profile. For example, occupations such as Air Traffic Control Radar Controller, and Interrogator must be able to hear a wide range of human voice tones. Infantrymen must be able to hear oral commands in outdoor areas from distances up to 50 metres.

4.7 U.S. Navy Hearing Standards (NAVMED 1980 and 1984)

At present, U.S. Navy flight training candidates must have HLs in both ears not exceeding 25 dB at 500, 1000 and 2000 Hz, 45 dB at 3000 Hz, and 60 dB at 4000 Hz. Qualification for commission requires the average HL at 500, 1000 and 2000 Hz not to exceed 30 dB, and no single frequency to exceed 35 dB. HLs at 3000 and 4000 Hz cannot exceed 45 and 60 dB respectively.

4.8 U.S. Coast Guard

The U.S.C.G. hearing criteria for appointment, enlistment and induction are an average HL not exceeding 25 dB at 500, 1000 and 2000 Hz and no single frequency greater than 35 dB, and HLs not exceeding 45 dB at 3000 Hz, and 60 dB at 4000 Hz.

4.9 Royal Australian Navy (RAN)

The Royal Australian Navy specifies hearing standards in terms of the ear with the poorer HLs. Hearing Standard 1 (HS1), for example, permits HLs not greater than 15 dB at 500 Hz and not greater than 25 dB at 1000, 2000 and 4000 Hz in the poorer ear. In addition, acoustic specialist occupations require frequency-discrimination capability of ± 30 Hz at 1000 Hz (Anon, 1991).

5. DISCUSSION

Examination of the standards summarized above indicates that only three fall within the low-fence ranges shown in Table 1: the H&W Canada Class 1, the CF Hearing Categories H1 and H2, and the RAN Category HS1. Of these, the CF and RAN standards are the most stringent, specifying HL requirements at individual frequencies, rather than an average HL across a range of frequencies, and not permitting hearing aids for the H1 and HS1 categories. The other military standards miss the low-fence range in that they are more tolerant of hearing loss at 3000 and 4000 Hz. In this regard, Hétu (1994) has noted that frequently occupational requirements involving auditory capabilities have been based on medico-legal definitions of hearing that were adopted to compensate employees affected by noise-induced hearing loss.

As noted, many of the above standards permit the use of hearing aids[3]. Certainly, persons whose losses are primarily conductive and use a well-fitted and properly adjusted conventional (non noise-reduction) hearing aid can understand speech almost as well, as do persons with normal hearing, at least in the absence of high levels of extraneous sound.

Substantial advances have been made both in the development of improved hearing aids utilizing digital electronics and signal processing. The results of research on multichannel systems and on noise-reduction techniques suggest that the new hearing aids will be able to overcome, in part at least, the degradation of the acoustical signal between a speaker and a listener in situations where competing sounds and reverberant conditions are less than ideal (CHABA, 1991). It is not clear, however, how well these new technologies can ameliorate the speech-perception in noise problems experienced presently by individuals with severe sensorineural impairments (Van Tasell, 1993).

Interestingly, the difference between the H&W Class 1 and Class 2 requirements is one of binaural capability. An individual with a unilateral or asymmetrical hearing loss, as is possible with the Class 2 criteria, may achieve some degree of localization by moving his or her head. However, the person may not gain the advantage in understanding speech in noise or competing voices when the speech and the interfering sound come from spatially separated sources (Del Dot *et al.*, 1992).

The question that has not been resolved in the literature is whether a listener with a mild to moderate unilateral sensorineural hearing loss, who wears a hearing aid to attain bilateral-loudness balance, can localize effectively (Laroche, 1994). It is well known that sensorineural hearing pathologies can result in diminished frequency selectivity through a broadening of the auditory filters (Patterson, 1976). Since localization in noise is determined to a great extent by the frequency resolving ability of the ear (Canévet *et al.*, 1986), individuals with sensorineural hearing losses may be limited in their ability to localize sound sources in noise (Hétu, 1994).

6. CURRENT CANADIAN COAST GUARD HEARING REQUIREMENTS

The Canadian Human Rights Act (Anon, 1989) prohibits any policy or practice that deprives an individual or class of individuals of any employment opportunities on a prohibited ground of discrimination. The Act points out, however, that it is not a discriminatory practice to refuse, exclude, suspend, limit, specify or prefer in relation to any employment if the employer establishes the practice to be based on a *bona fide* occupational requirement.

Currently, CCG seagoing personnel are required to meet the H&W Class 1 pure-tone threshold hearing standard. The H&W Assessment Guide notes, however, that pure-tone audiometry is seldom directly relevant to an occupation and should only be regarded as an indicator of hearing ability. A major thrust of the CCG medical review program, then, is to ensure that the procedures and criteria for assessing the ability of individuals to perform their duties are realistic and are based on the hearing requirements of these duties.

Within the CCG, ships' officers and crew work in a number of

3. Although not specified in the H&W or CF standards, an individual needing the amplification provided by a hearing aid to meet a required Class or Category should be tested wearing the hearing aid. Audiometer pure-tone stimuli are presented to the individual from one or more loudspeakers within a sound-treated room in which reverberation and the entrance of extraneous sounds are kept to a minimum (ANSI, 1977).

disciplines. These include deck, radio, engine, logistics/supply, electronics/electrical, utility seamen and training instructors, and college cadets. In deck, engine and logistics duties, officers and crew are required to understand or discriminate orders and instructions that are directly spoken or shouted, as well as voice and tone signals from radios, telephones, bells, whistles and various types of alarms (CCG, 1990).

It can also be important for officers and crew to be able to identify changes in sound characteristics and the direction from which sounds emanate. The former, for example, is relevant in terms of identifying both normal and abnormal variations in machinery and engine sounds. The ability to localize the directional component of sound may be required to identify the position of buoys during reduced visibility. These auditory requirements can be continuous during sustained operations, and are frequently carried out in proximity to constant high levels of noise.

7. RECOMMENDATIONS

Identifying hearing requirements for CCG seagoing personnel should involve a detailed ergonomic task analysis of the auditory components specific to each officer and crew function, taking into account crew-station ambient-noise levels and the acoustic characteristics of ships' communications equipment. The analysis would incorporate a complete description of the auditory task including time on the task, work load, the criticality and frequency of the task, types of potential errors as a result of missed communications, and the consequences of such errors relative to mission safety and crew performance.

This type of analysis would serve two purposes. First, it would provide the task detail that may be missing in typical job descriptions, including requirements for auditory capabilities such as binaural hearing. Second, an analysis of auditory requirements would provide an operational framework for evaluating the hearing-perception capability of the individual who wears a hearing aid to maintain a required level of hearing, or the individual whose hearing has dropped below the required level and does not wear a hearing aid. The H&W Assessment Guide points out that a person's inability to meet rigid standards under artificial conditions (e.g., clinical pure-tone threshold testing) should not call for automatic rejection or for restricted employment (Anon, 1994).

Accordingly, it would be necessary to carry out pre-employment and periodic speech-discrimination and localization tests of these individuals, with their hearing aids, in realistic noise and/or reverberation environments. The results would be used in conjunction with auditory task-analysis data to make a reasonably founded assessment of the individual's ability to perform his or her duties.

Careful consideration must also be given to experience and skill sets which have been developed and refined over years of service. Individuals can learn sophisticated coping strategies to deal with communication and performance in noisy environments (Acton, 1970). In these cases supervisory assessment of the individual's ability to fulfil task requirements should be an important consideration.

Abel (1993) has employed two tests that are particularly sensitive in assessing speech-discrimination problems in realistic noise conditions. In the first, the Four Alternative Auditory Feature Test (FAAF) (Foster and Haggard, 1979), the listener is presented with four printed words, and on hearing a spoken word, responds by choosing one of the four alternatives. The stimuli and alternative responses have been chosen so that errors (e.g., first- or last-consonant discrimination errors) reveal speech-perception performance in terms of a set of acoustic, phonetic and perceptual features rather than simply the percentage of consonant targets that are heard correctly.

The second, the Speech Perception in Noise Test (SPIN) (Kalikow *et al.* 1977), consists of sentences which are presented in babble-type background noise. The listener's response is the final (key) word in the sentence. The sentences are of two types: high-predictability items for which the key word is somewhat predictable from the context, and low-predictability items for which the key word cannot be predicted from the context.

Both of these tests are commercially available on tapes and can be administered in any hearing-science laboratory or audiology clinic. At present, there are no standardized procedures for the evaluation of localization capabilities (Laroche, 1994). Before a complete and valid auditory assessment can be made of a hearing-impaired individual seeking to gain or retain employment in occupations involving particular listening skills, relatively simple tests must be developed for all the required skills, taking into account unilateral and bilateral hearing losses and the use of hearing aids.

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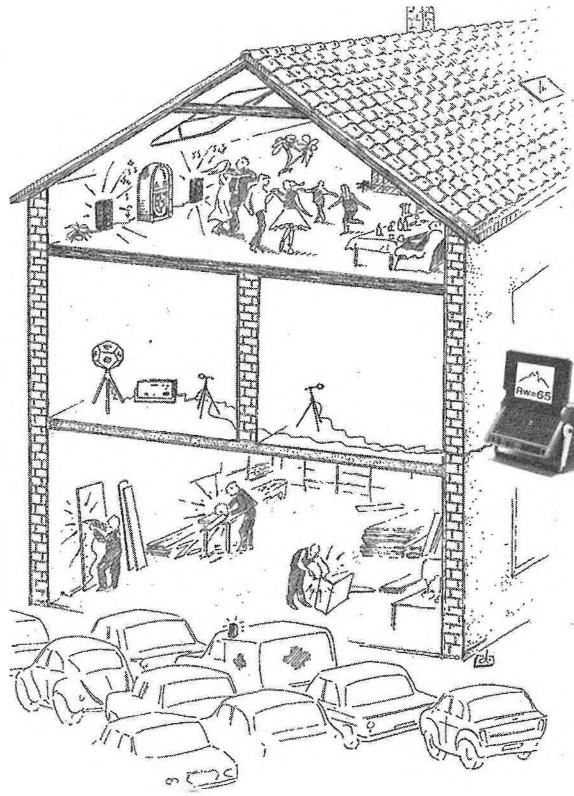

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