ESTIMATES OF SPEECH INTELLIGIBILITY BASED ON EQUIVALENT SPEECH- AND NOISE-SPECTRUM LEVELS AND HEARING THRESHOLDS

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1. INTRODUCTION

This paper describes the speech-reception phase of a multi-phase project to determine the hearing requirements of Canadian Coast Guard (CCG) seagoing operations. The aim of this phase was to obtain an estimate of the beginning of "hearing handicap" (low fence) for speech discrimination in the acoustical environments of CCG vessels.

The fence, defined in terms of hearing threshold levels (HTL), would represent the minimum hearing needed to meet the CCG medical entrance requirement. Individuals not meeting the HTL requirement would undergo otological examination and audiological evaluation, including speech discrimination testing in noise, to provide a suprathreshold assessment of their hearing capabilities (see companion paper, Ritmiller *et al.*, 1999).

An estimate of the fence was obtained using engineering and psychoacoustical procedures that were supported by experimental data. The procedures included Speech Transmission Index (STI) data processing for the determination of equivalent speech- and noise-spectrum levels (see companion paper, Hodgson *et al.*, 1999), and the Speech Intelligibility Index (ANSI S3.5-1997).

2. SPEECH INTELLIGIBILITY INDEX

The ANSI S3.5-1997 Standard is a updated version of the 1969 procedure (Articulation Index (AI)) for calculating a physical measure that is highly correlated with the intelligibility of speech under a variety of adverse listening conditions (e.g., noise, filtering and reverberation). To identify the revision, ANSI renamed the procedure *Speech Intelligibility Index (SII).*

The SII is calculated using octave or one-third octave-band noise and speech spectra and the hearing loss of a listener. Hearing loss is treated as a fictitious internal noise which, if it were an external masker, would result in the same masked threshold. The speech-to-noise ratio (S/N) in a given frequency band, within the range 0 to 30 dB, determines the degree to which the speech signal in the band contributes to intelligibility. Each band is weighted with an importance function representing the contribution to intelligibility of the band. The SII can be interpreted as a proportion of the total speech cues available to a listener. The maximum value of the SII is 1.0 and signifies that all speech cures are available to the listener. Its minimum value is 0.0 and signifies that no cues are available.

Although the AI/SII provides good predictions of speech intelligibility under various conditions of filtering, noise distortion, and low speech level, the studies of Pavlovic (1984) indicate that the procedure over estimates the speech-discrimination ability of individuals with severe sensorineural impairment. He concluded that if a correction factor were to be applied to the frequency importance functions, the resulting AI/SII predictions for sensorineural-impaired individuals would be improved (Pavlovic *et al.*, 1986). The corrected importance function is given by:

$$C_i = 1.19 - 0.0127L_i \qquad \text{for } 15 < L_i < 94,$$

where C_i is the importance function for the (i)th frequency band and L_i is the hearing loss (dB HTL) in the (i)th band. The SII determinations carried out in this study were corrected using the above equation and are designated as SII(C).

3. DEVELOPMENT OF HTL PROFILES

An array of hearing losses was prepared to encompass the range within which the low fence was likely to occur. Twenty profiles were defined, based on the epidemiological data published in ISO Standards 7029 (1982) and 1999 (1988), and represent typical manifestations of noise-induced and age-related hearing losses. The resulting HTLs at .5, 1, 2 and 4 kHz for five of the profiles are shown in Table 1, illustrating the extent to which hearing loss increases with profile number. These profiles were also used in the signal-detection phase of the project (see companion paper, Laroche *et al.*, 1999).

TABLE 1: Hearing thresholds in dB for five of the HTL Profiles at the four frequency bands that are most important for speech intelligibility.

PROFILE	.5 kHz	1 kHz	2 kHz	4 kHz
1	9	9	11	14
6	10	10	22	28
12	11	13	38	43
15	13	16	45	50
20	17	22	58	60

4. RESULTS AND DISCUSSION

Acoustical data files, comprised of equivalent speech- and noise-spectrum levels, were obtained for a number of ships' operating conditions and work areas in which speech-communication tasks had been identified as critically important (Ritmiller *et al.*, 1999). An array of SII(C) values was computed for each data file using the 20 HTL profiles. Table 2 shows a typical array. The SII(C) values descend from 0.79 (Profile 1) to 0.48 (Profile 20).

A number of investigators have produced estimates of the HTL at which persons begin to lose speech perception. Acton (1970) and Suter (1985) noted that the selection of a fence depends on the definition of hearing handicap and the conditions under which the handicap is assessed. Smoorenburg (1986) defined the onset of hearing handicap as the point at which an individual begins to notice a handicap in everyday noisy situations. Robinson *et al.*

(1984) concluded that a threshold of handicap is dependent on the difficulty of the listening task, and hence the selection of any one set of conditions for the definition of handicap is necessarily arbitrary. The estimates of the low fence determined by these investigators are summarized in Table 3.

TABLE 2: A typical array of SII(C) values.

HTL PROFILE	SII(C)	HTL PROFILE	SII(C)
1	0.79	11	0.64
2	0.78	12	0.63
3	0.76	13	0.61
4	0.75	14	0.59
5	0.74	15	0.58
6	0.72	16	0.56
7	0.70	17	0.55
8	0.68	18	0.54
9	0.67	19	0.52
10	0.65	20	0.48

TABLE 3: Estimates of the low fence for speech discrimination in terms of mean HTL, averaged across specified audiometric test frequencies.

AVERAGE HTL	FREQUENCY RANGE	SOURCE
19 dB	1, 2, 3 kHz	Acton (1970), Suter (1985)
27 - 34 dB	1, 2, 3 kHz	Robinson *et al.* (1984)
30 dB	2, 4 kHz	Smoorenburg (1992)

TABLE 4: US Army MIL-STD-1472 intelligibility requirements in terms of the Articulation Index (AI) (Anon, 1981).

COMMUNICATION REQUIREMENT	AI
Exceptionally high intelligibility (separate syllables understood)	0.7
Normally acceptable intelligibility (separate syllables understood, about 98% of sentences heard correctly, single digits understood)	0.5
Minimally acceptable intelligibility (limited standardized phrases understood, about 90 % of sentences heard correctly; not acceptable for operational equipment)	0.3

The implications of setting a low fence must be considered carefully. A fence that is unnecessarily restrictive will require a number of the candidates seeking employment to undergo otological and audiological assessment that would not otherwise be required. A fence that is too permissive may result in persons performing critical communication tasks who are not able to perceive speech in noise adequately. With reference to the communication requirements given in US Army MIL-STD-1472 (Table 4, Anon (1981)), it was concluded that a SII(C) cut-off in the range 0.50 and 0.60 would meet the CCG hearing requirements.

The HTL profiles occurring at SII(C) cut-off values equal to 0.50 and 0.55 were averaged across the critical speech-communication task results. The resulting mean HTL profiles and their corresponding hearing thresholds fell within the range of the low-fence estimates summarized in Table 3.

5. ACKNOWLEDGEMENT

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