Validation of masked threshold predictions among people with sensorineural hearing loss

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Auditory capacities are a given. This situation calls for efforts to adapt the work environment to the prevailing residual capacities of workers with a hearing impairment. Noise reduction is of course the first step required in order to improve signal-to-noise ratios. However, in many cases, these steps will not be sufficient to prevent performance impairment among workers with a hearing loss. Specific procedures for job accommodation are warrented.

With respect to auditory warning signal detection, given a certain ambiant noise, one needs to predict the signal level at a given frequency that will meet the individual's detection capacity. Previous work has been done to adapt a laboratory procedure for measuring frequency selectivity to the constraint of a clinical test [1-2], and also to adapt Dectect*sound*™ [3] to individual rather than statistical predictions of masked thresholds. The present investigation aimed at validating such predictions among people with various degrees and configurations of sensorineural hearing loss.

Methods

Participants

Participants were sampled in order to represent different degrees of sensorineural hearing loss lower than 75 dB HTL and different audiometric configurations. They were recruited among the clients of a regional audiological rehabilitation center in Montreal, using the following exclusion criteria: (a) air-bone gap greater than 10 dB between 0.25 and 4 kHz; (b) abnormal tympanogram; (c) interaural difference in hearing thresholds greater than 35 dB between 0.5 and 4 kHz; (d) maximum loss between 0.25 and 4 kHz greater than 75 dB HTL [53]; (e) the over-65 or under-18 age brackets; (f) presence of a disease associated with fluctuating hearing thresholds.

Inclusion criteria were determined according to audiometric configuration, that is, based on the difference between average hearing thresholds in the high frequencies (2, 3 and 4 kHz) and the low frequencies (0.25, 0.5 and 1 kHz). 'Descending loss' was defined as a 10 dB difference between the high and low frequency average threshold, the inverse being the case for 'ascending loss'. 'Flat loss' referred to a difference inferior to 10 dB. Four groups were thus recruited as follows:

- 13 individuals with a descending maximum loss of between 35 and 55 dB HTL;
- 21 individuals with a descending maximum loss of between 55 and 75 dB HTL;
- 6 individuals with an ascending maximum loss of 55 dB HTL;
- 12 individuals with a flat loss of between 30 and 55 dB HTL.

Procedure

The experimental setup was identical to the one used in a previous study [4] with white noise filtered by two lowpass and two highpass filters connected in series. The continuous notched noise was combined with a 250-ms pulsed pure tone repeated every 500 ms that was generated by a clinical audiometer and presented to the subject by means of a TDH-50 earphone. Masked thresholds were assessed by Bekesy tracking during 30 seconds per notch noise condition.

Auditory filters were assessed at 0.5, 1, 2, 3 and 4 kHz respectively in a random order. The masking noise conditions were also randomly presented except for the first condition, which was always the allpass noise ($g_l = g_u = 0.0$). Testing was initiated with the masking noise level set at 40 dB/Hz. When the allpass noise induced less than a 5-dB masking effect, the noise level was set at 50 dB/Hz. In order to avoid aberrant estimates of the filter slope on the high frequency side [2], masked thresholds were also assessed with six highpass noise conditions ($g_u = 0.0; 0.1; 0.2; 0.3; 0.4; 0.5$) when estimates of p_u resulting from notch noise testing were greater than 50. The auditory filters were characterized using the mathematical expressions proposed by Glasberg and Moore [5].

In order to test the validity of predicted masked thresholds from individual auditory filter characteristics, the 52 participants were asked to detect pure tone signals at 0.5, 1, 2, 3 and 4 kHz in three spectra of broadband noise (lowpass, highpass and bandpass [1]) at 85 dBA, in addition to the allpass white noise at 78 dBA used in auditory filter characterization.

Results and discussion

Considerable individual variations were observed in the detection thresholds with the four broadband noise conditions tested. Where the noise spectrum is flat, no relationship emerges between masked and absolute threshold level, as expected. There are nevertheless difference of approximately 15 dB between the higher and the lower masked thresholds.

Where the noise spectrum is sloping, there appears to be an association between absolute and masked threshold, above a certain value of absolute threshold: namely, above 35-40 dB HTL at 0.5 kHz and above 50 dB at 3 kHz. This is attributed to filter asymmetry and to upward spread of masking effects, which is more likely with poorer hearing sensitivity. With the lowpass noise showing a maximum slope around 3 kHz, the staggering of individual data is pronounced: a 41 dB difference is observed between extreme values. These large variations confirm the need for individual adjustment of auditory signals with respect to the residual capacities of hearing-impaired workers.

Table 1 presents the means and standard-deviations of the differences between predicted and observed detection thresholds within the four masking-noise conditions. Only those cases where the filter was actually characterized are included. As expected, the procedure generally leads to slight overestimations of the masked thresholds, the average error of prediction being smaller than 2 dB, with one exception, that is, 2.15 dB at 0.5 kHz with the white noise. The range in individual errors is relatively small (i.e., the standard-deviations of differences were smaller than 4 dB), with two exceptions: at 4 kHz with lowpass noise, and at 2 kHz with bandpass noise. With allpass noise, which actually served to assess the value of the fitting constant K, such errors are minimal.

As can be seen from Figure 1, the magnitude of individual prediction error is typically 2.5 or 3 dB in a majority of cases, and is rarely above 5 dB, a value that is compatible with the audiometric measurement error. In fact, the proportion of cases of underestimation by 5 dB or more is equal to 0, 3.5, 4.6 and 6.4% for the allpass, lowpass, highpass and bandpass noises respectively.

Table 1. Mean and standard-deviation (S.D.) of the differences between predicted and observed detection thresholds in four different masking noises. N refers to the number of individuals with whom the auditory filters had been measured.

		Signal frequency - kHz				
		0.5	1	2	3	4
Allpass noise	Mean - dB	2.15	1.78	0.93	1.36	0.63
	S.D. - dB	0.88	0.91	1.04	1.06	1.16
	N	40	48	40	32	28
Lowpass noise	Mean - dB	1.08	1.31	0.53	0.76	0.66
	S.D. - dB	2.69	2.36	3.25	2.88	4.10
	N	37	44	36	29	27
Highpass noise	Mean - dB	-0.01	-0.02	-0.44	1.66	0.47
	S.D. - dB	3.70	2.17	3.61	2.82	3.03
	N	37	44	36	29	27
Bandpass noise	Mean - dB	0.41	0.86	-1.11	1.48	0.99
	S.D. - dB	3.89	2.61	4.41	2.70	3.91
	N	37	43	36	29	27

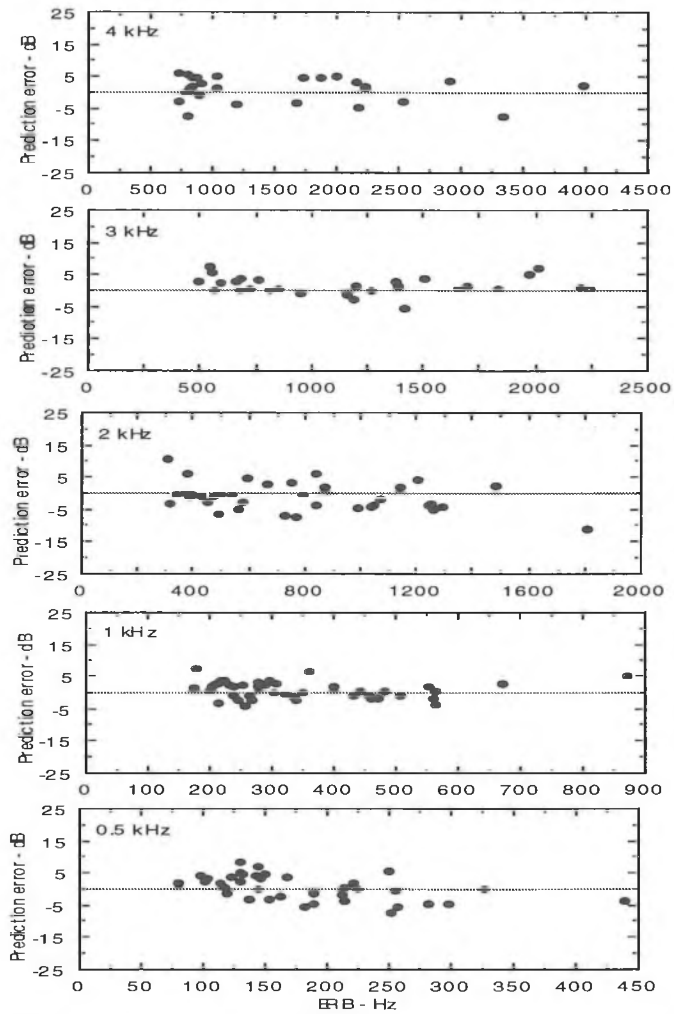

Figure 1. Individual values of the differences between predicted and observed thresholds masked by the bandpass noise.

The findings indicate that the errors tend to increase with signals located in the sloping portion of the noise spectrum. In those specific circumstances, the masked threshold depends not only on the overall width of the auditory filter but also on its shape. Assessing the slopes of the filters involves much more uncertainty than assessing only their width. This is especially true when the filters tend to be highly asymmetrical, as is often the case with descending audiometric configurations.

Guidelines for auditory warning signal design prescribe signal level adjustment at 15 dB above the estimated masked threshold in order to ascertain attention demand and facilitate signal recognition. As errors of underestimation in individual masked threshold predictions are equal to or less than 5 dB for a very large majority of cases (Table 1), the use of the present procedure would ensure signal detection for almost anyone whose auditory filters have been characterized. Some individuals might, however, be at a slight disadavantage with respect to signal recognition.

Generally speaking, the present endeavour demonstrates the feasibility of adapting the most common auditory demand in the industrial workplace, namely, sound warning signal detection, to the constraints imposed by a heairng loss. A clinical procedure allows one to characterize, in 15 to 25 minutes of testing time, the residual capacity for signal detection in noise in the better ear of an individual who suffers hearing loss. A computer model (*Detectsound*™) provides the required specifications in terms of signal level adjustment. The testing procedure together with the model constitute, in our view, a practical tool for job accommodation with people who sustain a hearing loss.

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