DEVELOPMENT OF STANDARDS FOR HEARING-CRITICAL JOBS

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Introduction The Canadian Coast Guard (CCG) and Conservation and Protection (C&P) Departments of Fisheries and Oceans Canada are reviewing their medical standards to better define critical components of medical fitness essential to safe and effective marine operations. CCG and C&P jobs are hearing-critical (HC), and share several features. They are often performed in noisy environments, and involve a number of common functional hearing abilities such as speech communication, sound detection and localization. Individuals who lack these abilities may constitute a safety risk to themselves or to fellow workers, and the general public. Research is underway to ensure that the minimum medical standard for hearing is appropriate for these hearing-critical jobs, and that this standard is based on empirical evidence defendable in court.
A number of quantitative models have been developed to predict functional hearing ability on the basis of diagnostic measures of hearing such as pure-tone audiograms. While these models may have significant research value, they lack sufficient accuracy to predict real-life performances of individuals from which decisions and actions regarding hearing-critical jobs can be based [1,2]. A potentially more accurate alternative approach has been used in this project. Diagnostic measures of real-life hearing abilities have been replaced with simple computerized screening measures of functional hearing in reference noises. These screening measures can be administered quickly over headphones. Sound field versions are also available in cases where hearing aids or other devices are worn. Through statistical modeling, performance on the screening measures exhibits a direct empirically based relationship to occupational auditory performance in the actual noise environments of the CCG and C&P. In addition, the screening tests have adequate and well-defined psychometric properties, i.e., reliability, sensitivity, and validity, so that screening test results accurately predict the individual's ability to perform critical auditory skills in the noise environments associated with the hearing-critical tasks.

Development and validation of the predictive model: Development and validation of the model for predicting functional hearing ability in real-world noise environments where HC jobs are performed followed a five-step process. These steps are listed below. In the remainder of this paper we summarize the methods and results for each of these steps.

1. Identify hearing requirements and measure noise environments during HC jobs;
2. Identify screening measures of functional hearing abilities;
3. Relate screening measures to performance in real noise environments for normal-hearing individuals via laboratory studies;
4. Validate the relationship of screening measures to functional hearing abilities in HC noise environments; and
5. Apply the model to establish functionally based criteria for HC jobs.

Step 1. Identify hearing requirements and measure noise environments during HC jobs: Job content experts (JCEs) were asked to identify the hearing-critical tasks and the workplace locations where these tasks are performed. These tasks comprised sound detection, sound localization, and speech communication; however, in this paper we limit our discussion to the

speech communication tasks. The JCEs were also asked to specify performance parameters for each communication task. Parameters included the expected voice level and distance of the communication, and whether repetition of the communication or command was possible. The research team then went on different vessels, as well as in land and air operations to record the noise environments where CCG and C&P employees perform HC tasks [3]. After the recordings were completed, the JCEs assisted in classification of the 112 noise recordings taken into 15 locations summarizing the range of environments relevant to CCG and/or C&P jobs. Noise recordings were analyzed and sampled to create audio files for use in laboratory simulations of the real noise fields (Steps 3 and 4).

Step 2. Identify screening measures of functional hearing ability: Based on the HC tasks identified by the JCEs, the research team in conjunction with the JCEs identified specific auditory abilities required for each task. These abilities were speech communication, sound localization, and sound detection. The research team was tasked to identify screening measures that could be administered under headphones or with loudspeakers in the sound field to assess these abilities. The Hearing In Noise Test (HINT) [4] was chosen as the measure of speech communication because it can be used with an adult population, is available in English and Canadian French, uses sentence material, has known psychometric functions, can be administered monaurally or binaurally, uses recorded voice, and can be administered with headphones or in free-field in quiet or noise. The detection and localization portions of the Source Azimuth Identification in Noise Test (SAINT) were chosen as the measures of sound detection and sound localization for much the same reasons as the HINT (except for the language criteria) [5].

Step 3. Relate screening measures to performance in real noise environments for normal-hearing individuals via laboratory studies: Figure 1 shows the sequence of tasks performed for this step. Beginning with the screening measures and protocols and the re-created noise environments from Steps 1 and 2 (as shown in the upper left of Figure 1), a sample of 45 normal hearing subjects were first administered the set of screening measures both under headphones and in the sound field. These same subjects then performed speech intelligibility, sound detection and sound localization tasks in the 15 noise locations identified earlier. Each subject was tested in three locations at three signal-to-noise (S/N) ratios. The S/N ratios were chosen to produce high, medium, and low levels of expected accuracy for each task. The same stimuli (HINT sentences, human vocalization, and gunshot) were used for the HINT and SAINT screening measures and for the tasks in the re-created CCG and C&P noise environments.

The data from all subjects and all locations were analyzed and pooled according to a predetermined sequence of steps. These steps are described only for the speech communication measures in this paper, although the same steps were followed for the other measures as well. First, the location S/N ratios used in the intelligibility tests were normalized by the subject's composite HINT score from the screening measures. For example, if a subject's composite HINT threshold was 3 dB above the composite norm, 3 dB was subtracted from the location S/N ratios for that subject. By normalizing the intelligibility scores in this fashion, individual differences in speech communication ability, as determined from the HINT screening measures, are minimized in the pooled data for each location. These pooled data were evaluated in scatterplots of intelligibility displayed as a function of normalized S/N ratio, and extreme outlier data points were rejected. Approximately 5% of data was screened in this manner. Extreme outliers were assumed to have been due to lapses of attention by the subject (or the experimenter).

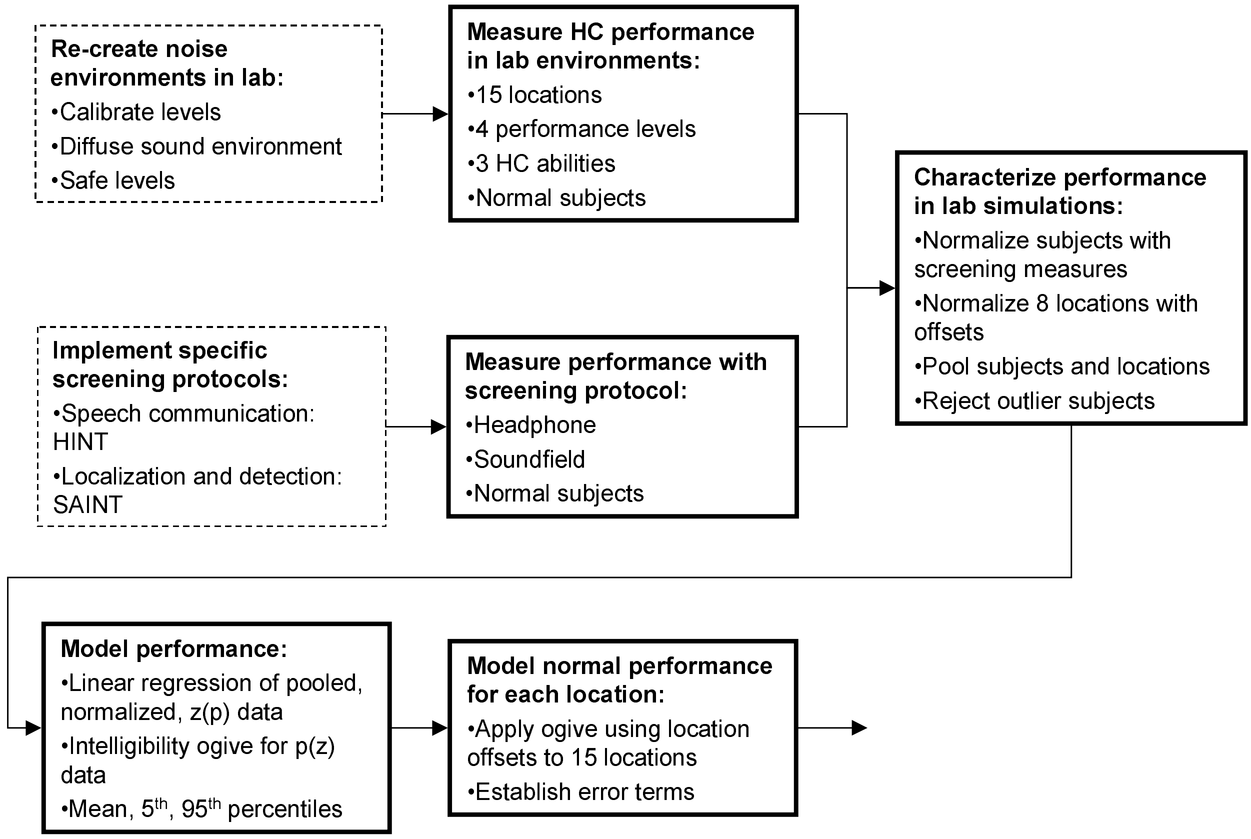

Figure 1. Tasks for development of a statistical model to predict functional hearing ability in CCG and C&P noise environments from screening measures.

The pooled, normalized, screened data were evaluated for each location, and 8 of the 15 locations exhibiting the most consistent relationship between S/N ratio and intelligibility were chosen for use in development and validation of the statistical model. A subset of locations was used because of practical considerations: location data sets with highly variable relationships between S/N ratio and intelligibility provide a weak means of validating the model. Since large amounts of human subject testing time are required for validation, our objective was to utilize testing time most efficiently by selecting locations that provide the greatest statistical power for validation of the model. For each of the selected locations, the percent intelligibility scores were linearized with the z transform, and the linear regression of intelligibility z scores on S/N ratio was calculated. The S/N intercept of the regression function was used as to define the location offset for each location In other words, the intelligibility z score function was shifted by an amount equal to the estimated S/N ratio for 50% correct performance for each location. After subtracting the location offset from the S/N ratios for each location, the z transformed data from each location were pooled.

The function relating normalized intelligibility z scores to normalized S/N ratio was developed by computing the linear regression of the z scores on S/N ratio for the 8 locations. This regression equation accounted for 0.67 of the variance, $r = 0.82$, slope = 0.176 z/dB. The left panel of Figure 2 shows the z score distribution and regression function for the 8 selected locations. This linear regression function was transformed with the p transform to produce the traditional intelligibility ogive, as shown in the right panel of Figure 2. The middle ogive corresponds to mean predicted intelligibility (50th percentile). The ogives corresponding to the

5th and 95th percentile of the normal sample are also shown. These percentiles are positioned ± 2.5 dB on either side of the mean ogive. When this function is used to predict intelligibility for the entire set of 15 locations, 0.49 of the variance in intelligibility is accounted for (r = 0.70) and the 5th and 95th percentiles are positioned ± 4.4 dB on either side of the mean. The loss of predictive accuracy can be traced to 3 of the 15 locations, where the variance accounted for was less than 0.20. The noise characteristics from these locations are being examined to determine whether aspects of the noise that might contribute to the variability can be identified.

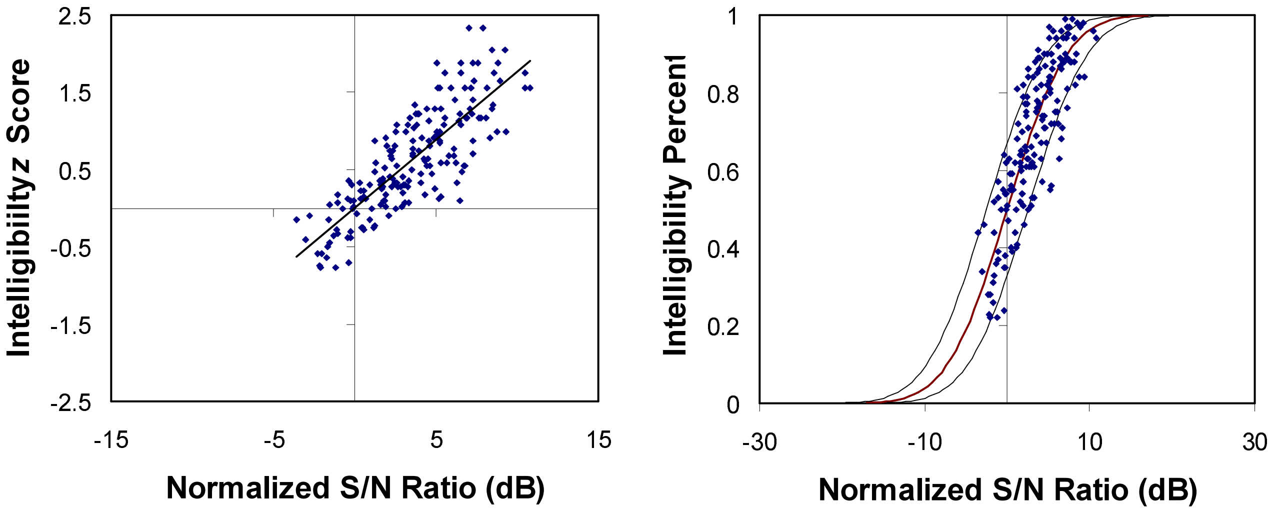

Figure 2. Intelligibility z scores and percents as function of S/N ratio for 8 locations.

Step 4. Validate the relationship of screening measures to functional hearing abilities in HC noise environments: Work related to this step and the following is still underway. The validation of the model can be divided into two logically separate parts. The first aspect of the model's validity relates to its accuracy in predicting intelligibility for other normal hearing individuals, and for individuals with hearing impairment. The predictive accuracy for normals is addressed through cross-validation. The initial sample of normals will be divided into two randomly formed groups, and the model will be re-developed for each group and applied to the other group. Within- and across-group accuracy for normals will be compared. We anticipate a very small loss of accuracy when the model is applied across groups of normals, given the homogeneity and variability of the data set seen in Figure 2. The validity of the model for hearing impaired individuals will be determined from results for a new sample of hearing impaired individuals. Subjects in this study will first receive the HINT screening measures, and their composite score will be computed. Previous research has shown that hearing impairments elevate HINT composite scores, shifting the subject's intelligibility ogive to a higher S/N ratio. The subject's composite score will be used to predict intelligibility at specified S/N ratios in noise samples from the 8 locations selected in Step 3. An example is shown in an accompanying paper [6]. The subject will be tested at these S/N ratios to allow comparison of their predicted and obtained intelligibility. Validation of the model for both normal and hearing impaired individuals is underway at present.

The second aspect of the model's validity relates to the correspondence between its predictions of performance in specific CCG and C&P job locations, and the performance parameters for HC communications specified for these locations by the JCEs. In this case, the model is used to

predict HINT composite scores needed to reach the performance levels specified by the JCEs. For example, the JCEs may specify that a particular HC task requires 90% accuracy without repetition of the command or communication and that most communications occur over a distance of 3-6 meters using a shouted voice. These parameters can be used to predict the level of the command or communication reaching the listener. This information, together with knowledge of shouted speech levels [7] and the measured noise levels for the location, allow prediction of the HINT threshold needed to achieve the specified communication accuracy. If the predictive models shows that better than normal performance on the screening measures is required to achieve the performance parameters, then either the model is inaccurate or the performance expectations are unrealistic.

Preliminary results indicate that the performance parameters defined by the JCEs for several locations appear to require "super normal" functional hearing abilities—a substantial portion of recorded noise intervals from these locations produce S/N ratios that prevent functionally normal individuals from achieving the specified performance. We surmise that tasks performed during these intervals utilize alternative communication strategies, e.g., visual signals, and thus (temporarily) are not truly hearing-critical. The noise statistics used in the predictive model have been modified to be consistent with this hypothesis. Noise intervals for which the performance parameters specified by the JCEs can not be reached by individuals with normal functional ability with hearing alone (and thus may not be hearing-critical) have been eliminated, leaving only those noise intervals in which normals can achieve the performance parameters at all times using only hearing. New analyses are underway to determine whether this re-definition of HC tasks is more consistent with the specifications of the JCEs.

Step 5. Apply the model to establish functionally based criteria for HC jobs: The final step will be to apply the model to establish the screening criteria for each task and each location. These criteria will be stated in terms of scores on the functional hearing screening measures, i.e., HINT and SAINT. This step will be done by the researchers in close collaboration with the JCEs. If the criteria differ largely from one task to the other or from one location to the other, the minimum criteria will have to be set according to the most demanding situations. CCG and C&P employees have to perform their tasks in different locations. If they want to perform at a safe level, they would have to reach the minimum criteria. If, for certain locations or tasks, the criteria are more stringent then what would be expected from a normal-hearing group, the normal criteria should be used. All the criteria and rationale will be finally validated with the sponsors to make sure that they are scientifically based and defendable in court.

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Keywords: Noise and communication, Hearing-critical jobs, Task performance, Functional hearing ability, Hearing In Noise Test, HINT, Source Azimuth Identification in Noise Test, SAINT

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