Establishment of fitness standards for hearing-critical jobs

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INTRODUCTION

In many occupational settings, medical standards are necessary to ensure that workers are fit to conduct safe and effective operations, given the specific task demands for each job. In occupations such as the military, the firefighting service, the coast guard, the police force and other law enforcement jobs, medical standards extend to the hearing modality (Hétu 1993; Laroche 1994; MacLean 1995; Forshaw & Hamilton 1997; Soli & Vermiglio 1999; Laroche et al. 2003). These occupations all require a number of functional hearing abilities or skills such as speech communication, sound detection and localization, which must often be used in noisy environments. A sufficient level of functional hearing ability is needed from each worker to prevent safety risks to themselves, to fellow workers, and to the general public. Some noise environments and task situations can at times be very challenging, and allowing workers with hearing loss in these workplaces is an important issue that must be addressed. Fitness for work, however, must not be based on the degree or configuration of the hearing loss as such, but on the ability (or inability) to perform the various auditory skills needed by the job at the required performance level, taking into account the relevant parameters of the listening environment for every task.

Unfortunately, occupational hearing standards are primarily based on simple diagnostic measures of hearing, such as the absolute hearing threshold at specific frequencies or the pure-tone average (Coles & Sinclair 1988; Hétu 1993; Bhérer et al. 2002). Such measures were originally designed to compensate workers for noise-induced hearing loss, and not to assess the minimum hearing abilities necessary to function effectively in the workplace. Moreover, these measures implicitly assume a strong relationship between auditory tasks and, more specifically, between hearing sensitivity measures and functional hearing abilities at particular supra-threshold levels. It is well known that individuals with essentially identical hearing sensitivity may have a wide range of speech recognition abilities in noise (e.g. Smoorenburg 1992; Soli & Vermiglio 1999; Killion & Niquette 2000; Laroche et al. 2005). Models of real-world auditory performance based solely on the audiogram would therefore predict identical speech communication abilities in the workplace for individuals with identical audiograms, and likewise for other auditory skills. Such a framework clearly lacks sufficient accuracy and specificity to serve as a basis for making employment decisions regarding individual workers (Coles & Sinclair 1988; Begines 1995; MacLean 1995; Bhérer et al. 2002), and it has been successfully challenged in courts as job discrimination in some cases (Laroche 1994; Laroche et al. 2003).

Recent applications have contributed significantly to moving away from simple diagnostic measures of hearing to assess fitness for work. Two such applications are described in this paper, including the establishment of hearing standards for the Department of Fisheries and Oceans Canada (DFO) and the evaluation of Royal Canadian Mounted Police (RCMP) members wearing hearing aids.

FUNCTIONALLY-BASED SCREENING CRITERIA FOR HEARING-CRITICAL JOBS BASED ON THE HEARING IN NOISE TEST

Rationale

In many occupational settings, the work environment is characterized by a wide range of noises. It is well established that speech recognition depends on the energetic (global level, spectrum, temporal fluctuations, etc.) and informational masking properties of the noise (Festen & Plomp 1990; Studebaker et al. 1994; ANSI 1997; Brungart et al. 2001; Rhebergen & Versfeld 2005), and thus functional hearing assessment procedures must ultimately take into account the specific noise environments in which HC tasks are performed in the workplace. One approach would be to screen each individual worker in each noise environment where s/he is expected to perform HC tasks. Such a strategy would be highly impractical and time-consuming as a screening measure, and could raise validity and reliability issues unless a prohibitive amount of testing could be conducted.

Instead, the approach adopted in this research is to use a well-established speech perception test with well-defined psychometric properties (i.e., sensitivity, reliability, etc.) and normative data as the basic single measure to screen individual workers. Through statistical modeling, scores on this screening test are then empirically related to speech recognition performance in the real-world noise environments where HC tasks are performed. Listening experiments in the different noise environments characterizing the workplace are still required with this approach, but only during the development and validation phases of the predictive model. The assessment phase for a worker only requires administration of the screening speech perception test itself, which is quick, reliable, and can be conducted in a wide range of audiological settings. Using this statistical approach, screening test results can be used to predict the individual worker's speech recognition ability in the different real-world workplace noises with a known amount of prediction error, which can be taken into account when establishing minimum standards and screening criteria.

Moreover, models attempting to relate clinical scores to real-world performance must not solely rely on an individual's measured abilities but also take into consideration the constant interaction of those abilities with various aspects of the environment (noise, talker, communication tasks) and rehabilitation process (technologies, environmental modifications, communication strategies, realistic expectations). Indeed, the complete communication situation from talker to listener needs to be taken into account, as illustrated in Figure 1. Factors affecting speech production (voice level and spectrum) include the gender (M, F), the speech material, the vocal effort (normal, raised, shouted voice) of the talker, the Lombard effect of naturally raising one's voice in noise, and the use of HPDs. The latter can affect speech production by reducing the amount of Lombard effect due to the reduction in the noise perceived by the talker as a result of the attenuation of the protector and the increase in the perception of one's voice caused by the occlusion effect of the device (Tufts & Frank 2003). Distance and reverberation modify the speech transmission process, whereas factors affecting speech perception include the hearing status of the listener, whether or not the message can be repeated, the spatial distribution of the speech signal and noise (or binaural unmasking), the intrinsic characteristics of the competitive noise and the use of hearing devices or HPDs.

Development of predictive model

To set hearing standards for the DFO personnel, a quantitative model was developed and validated to predict speech recognition performance in real-world noise environments from individual scores on the Hearing in Noise Test (HINT), which uses a stationary speech-spectrum noise. Performance-intensity (PI) functions were initially established using normal hearing individuals for 15 noise environments characterizing the various DFO job functions. The HINT was also administered and the noise composite score, which is the weighted average of the speech reception thresholds in the noise front, noise right and noise left conditions of the test, served as a single measure of speech reception in noise. Any deviation from the normative HINT composite score (English = -6.35 dB S/N; French = -7.18 dB S/N) represents the subject's speech recognition abilities in noise relative to an average normally-hearing individual. Such deviation is translated in the model as a shift in the PI function towards higher S/N ratios, thereby normalizing, on a per subject basis, the S/N ratios used during testing. Such normalization allows pooling the data from all subjects (46 English-speaking and 45 French-speaking) to derive PI functions in each noise environment. Further normalization using the environment-specific offset (representing the S/N ratio for 50 % word intelligibility for HINT sentences in the real-world occupational noises for a group of normally-hearing individuals whose HINT composite score is normalized to the language-specific norm) allowed pooling data from all noise environments and subjects to obtain a generalized PI function, as shown in Figure 2. The model was further validated using individuals with a wide range of hearing profiles (29 English-speaking and 30 French-speaking) by comparing predicted and measured intelligibility at specific S/N ratios in laboratory re-creations of each real-world noise environment.

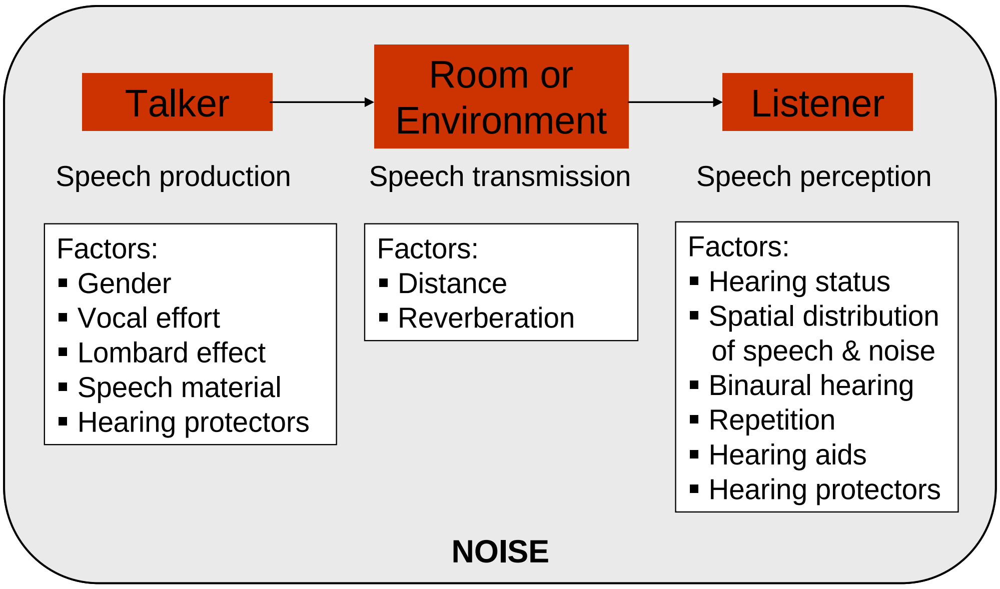

Figure 1: Speech communication from talker to listener in noisy environments

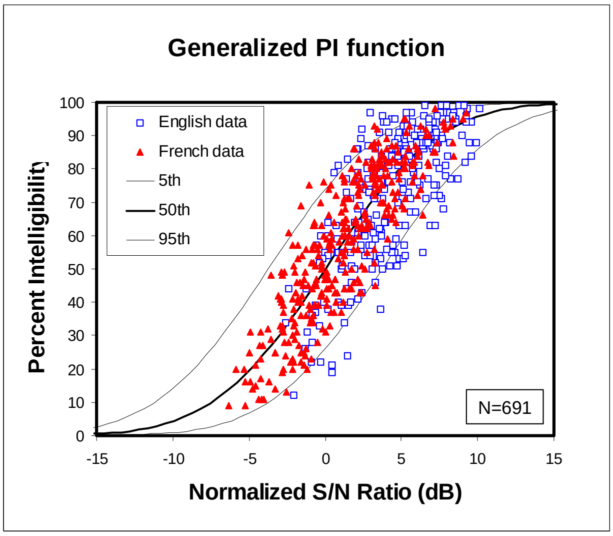

Figure 2: Generalized PI function, across all subjects and noise environments

Prediction of occupational performance

The generalized PI function allows predictions of the expected speech intelligibility score for given individuals as a function of the S/N ratio in each workplace noise environment. An example is provided in Figure 3. The curve representing the intelligibility performance in DFO Noise Location 1 for an individual scoring -2.0 dB S/N on the English HINT is obtained by shifting the generalized PI function by -9.9 dB (= location 1 offset) to the left and then by 4.35 dB (= HINT deviation relative to norm) to the right. This curve represents the word intelligibility score that can be expected from this individual as a function of S/N ratio in the specified noise environment.

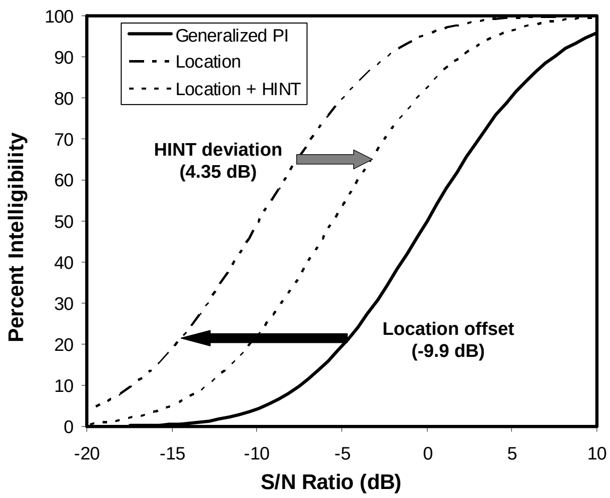

Figure 3: Use of the generalized PI function to predict speech intelligibility in DFO Noise Location 1 (fishing boats – fixer gear) for a listener scoring -2.0 dB S/N on the English HINT (composite)

In order to predict a more specific occupational performance, the actual S/N ratio available to the listener during each hearing-critical (HC) task must be specified. This requires knowledge of the expected speech level of the talker at the listener's position in various communication situations. It is well known that the vocal effort and acoustic output from a talker in face-to-face communications depends on the noise level in the environment, a phenomenon known as the Lombard effect (Lane & Tranel 1971; Summers et al. 1988; Junqua 1996). The voice level reaching the listener also depends on the distance between the talker and the listener.

The model was therefore based on published data on the Lombard effect (Pearsons & Bennett 1977) predicting conversational speech levels as a function of noise level for communications occurring at 1-meter distances. Typically, the model assumes that in background noises of 45 dB(A) or less, talker speech levels are constant at 55 dB(A) and thereafter increase at a rate of 0.6 dB per 1 dB increase in noise level until reaching 86 dB(A) – the level of sustained shouted speech. As speech levels increase at a slower rate than noise levels, the S/N ratio decreases gradually as the noise level increases. From the distribution of levels in each noise environment, the distribution of S/N ratios at the listener position can be established. The model can be adapted to allow the user to specify: 1) the vocal effort of the talker, by expanding it to include speech levels produced by shouted vocal effort (typically 86 dB (A) at 1 meter), regardless of the background noise level, 2) the effects of communication distance using basic acoustical principles (reduction in speech levels by 6 dB for every doubling of distance) and 3) the effect of repeating the communication.

By multiplying the distribution of S/N ratios for a given noise environment by the measured PI function, one can determine the expected speech intelligibility associated with each HINT score, as a function of the communication distance of the communication, the vocal effort used by the talker and whether or not the message was repeated. An individual's ability to understand speech in a wide range of noisy environments can therefore be predicted from HINT scores, for various scenarios. In occupational settings, Subject Matter Experts are critical in the process of attempting to predict performance or set hearing criteria as they have extended knowledge of the communication tasks required by the specific job and can specify the parameters surrounding these tasks (distance, voice level, expected level of performance).

Using the SME specifications and the modeling tools described above, a HINT screening score is derived in each workplace noise environment where the tasks can be performed. An example is provided in Table 1, for a few HC tasks. These thresholds indicate the maximum (worst) HINT composite scores required to ensure that workers would meet the minimum intelligibility level specified for the task. As shown, the HINT screening scores for a given HC task depend strongly on the acoustical characteristics of the noises. In cases where a worker must perform a specific HC task in all noise environments, the lowest (most stringent) HINT composite score from all environments is used for screening (last column of Table 1).

Table 1: Sample of different HC task communication parameters (vocal effort, distance, and repetition) in the DFO project, the minimum speech intelligibility performance specified by the SMEs, and English HINT composite screening threshold in each environment. Empty cells indicate that the given task is not performed in the specific environment. An "X" is inserted in cells where the performance level that cannot be met by normally-hearing individuals. These situations should not be used for screening the hearing of employees based on the definition of a HC task. The last column is the most stringent HINT screening score from each task.

Task name	SME specifications				Locations										Best screening score required
	Communication distance	Repetition	Voice level	Minimum intelligibility	RHIB/FRC	Main cabin/ Rescue room	Deck side rescue/ Rescue Zone	Deck front and mid	Buoy deck/ Winch room	Engine control room	General machine spaces	Bridge/Ships office/Radio room	Monkey island	Galley/ Accommodations	
	meters	yes or no	normal or shouted	%	5	6	7	8	10	11	12	13	14	15	
Communications on the Vessel	1	Y	S	90%	-2	-1	5	5	5	5	1	5	5	5	-2
Navigate the Vessel	1	Y	N	90%								2			2
Stand Watch	1	Y	N	90%								2			2
Launch Lifeboat or Life Raft/Abandon Ship	1	N	N	95%				X	-4						-4
Access and Egress to/from Helicopter	1	Y	S	60%				5							5
Don Lifesaving Equipment	1	Y	N	90%	-3	-3	-2	-2	2	-2		2			-3
Human Overboard	9	Y	S	90%	X		X	X	1			3	2		1
Organize and Allocate Duties for Fire Fighting Drill	1	Y	N	60%	-2	-1	3	3	5	3	-2	5	4	5	-2
Prepare to Fight Fire and Fight Fire	1	Y	S	95%		5	4	5	5	0	5	4	5	5	0

PROTOCOL FOR THE EVALUATION OF AUDITORY FUNCTIONS FOR RCMP MEMBERS

To set scientifically-based hearing standards knowledge of the HC tasks, the noise environments where these tasks are performed and the parameters surrounding these tasks (distance, voice level and expected level of performance) is paramount. To ensure public safety, employers may however need to make quick judgments on the operational status of their employees prior to or during efforts to set new hearing standards, as was the case for the RCMP.

To assist the RCMP in making more informed decisions regarding fitness to work in officers wearing hearing aids without detailed information regarding HC tasks, communication parameters and noise characteristics, a testing protocol has been proposed which includes unaided and aided soundfield measures of sound detection, speech perception and sound localization, in addition to standard audiologic evaluations. The Hearing in Noise Test (Nilsson et al. 1994; Vaillancourt et al. 2005) and a measure of sound localization (S.E.L.A – System for Evaluating Localization Acuity) are used in their clinical format to test members with the hearing aids set at the program and settings used on a regular basis in occupational settings.

The protocol is used to: 1) evaluate the auditory functions for individual RCMP members currently facing operational restrictions because they do not meet the hearing criteria set forth in the RCMP Hearing Policy and could therefore compromise the safety of others as well as their own, and 2) verify if hearing aids allow these members to carry out the necessary auditory functions required to safely perform their job. While individual results help the medical team at RCMP in making more informed decisions about the operational suitability of each member, a secondary objective is to use the overall results across all tested members, together with the complete description of hearing aid parameters used, to form a database that will hopefully help identify best practices in hearing aid fitting for optimal functional hearing abilities in the RCMP work environment.

Given that research-based hearing standards have not yet been established for the various jobs performed by RCMP members, unaided and aided member performances on tasks of speech perception in noise and sound localization are compared to the 5th percentile performance amongst individuals with normal hearing on these same tasks to determine operational suitability. Representing the poorest performances amongst a group of individuals with normal hearing, the 5th percentile was deemed an appropriate interim screening criterion. Typically, the criterion could not be more stringent than the 5th percentile as some people with normal hearing would not be able to meet the required performance level. On the other hand, a more lax criterion cannot be proposed until supported by further research to establish functionally-based hearing standards, using an approach similar to that previously used for the Department of Fisheries and Oceans Canada (DFO). Individuals who meet the interim criteria are deemed fit to carry out effectively the auditory functions required by their job. For others, operational restrictions can be maintained until the proper hearing standards are established, at which point their results can be compared to the set standards.

CONCLUSIONS

In recent applications of fitness for work, diagnostic measures of hearing have been replaced with simple computerized screening measures of functional hearing in reference noises. The proposed approach in setting hearing standards utilizes the individual's score in relation to the norm, as measured in reference noises in the screening test, to predict functional hearing ability in real-world noise environments.

The current research marks the first time that such a detailed modeling approach combining both speech production and perception parameters has been used to solve practical noisy workplace communication problems. Although the proposed approach addressed some components of the general model describing speech communication from talker to listener in noise (Figure 1), much work remains. The tools developed, while applicable to other occupational environments, require a substantial amount of human subject testing in the development and validation stages of the predictive model to establish the generalized PI function and location offsets relevant to the specific workplace noises under study. Work is currently undergoing to estimate these model parameters directly from the noise recordings using objective tools such as the Speech Intelligibility Index (ANSI 1997).

The current research also uncovered several areas where there is relatively little data in the literature upon which to base modeling. One such aspect is the effect of repeating a verbal command on speech perception (Thwing 1956; Haggard 1973; Clark et al. 1985). Recent research (Mercille et al. 2006) seems to indicate that the benefits of repeating a spoken message depends on the temporal structure of the noise, with more benefits being accrued for fluctuating than continuous noises. The Lombard effect appears equally dependent on the temporal characteristics of background noises, being greater for fluctuating than continuous noises (Giguère et al. 2006). In essence, model contributions from the Lombard and repetition effects would hence vary from one noisy environment to the next rather than be consistently applied across various work environments in the establishment of hearing standards.

Another aspect to consider is the effects of cognitive loading of the listener (Schneider 2004) during HC tasks. The wearing of hearing protectors may also affect speech perception (Berger 2000), and this would need to be accounted for in workplaces where noise levels exceed regulatory limits. Talkers wearing hearing protectors were also found to produce lower speech levels in noise than talkers not wearing them (Tufts & Frank 2003), and this could lead to particular speech communication problems in the workplace.

Finally, the model was previously applied to situations in which visual information (visual cues) was not available to the listener. Further developments of the model will include modeling the effect on speech intelligibility of, among others: visual information, attenuation provided by hearing protection, communication devices and informational maskers.

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