Modelling Speech Intelligibility in the Noisy Workplace for Normal-hearing and Hearing-impaired Listeners Using Hearing Protectors

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(Received 3 December 2009; provisionally accepted 14 April 2010; officially accepted 4 August 2010)

A speech intelligibility model was developed and validated for use in workplace environments with hazardous noise levels that require the use of hearing protection devices (HPDs). Two speech perception studies were carried out in laboratory simulations of eight workplace noise environments. The first experiment ($n = 32$ normal-hearing individuals) was used to develop a general model for speech intelligibility that can be tuned to the specific characteristics of the noise. The second experiment ($n = 35$) was used to validate the general model for use with listeners covering a wide range of hearing profiles (up to severe hearing loss) and wearing HPDs (earplugs or earmuffs). The model took into account the characteristics of the noise, the signal-to-noise ratio (SNR), the attenuation of the hearing protector, and the hearing status of the listener. Good prediction of speech intelligibility scores in noise with HPDs required the use of correction factors to deal with both audibility (threshold) and distortion (supra threshold) effects arising from hearing loss. Correction factors due to audibility effects were computed from the Speech Intelligibility Index and the pure-tone audiogram. Correction factors due to distortion effects were based on the Hearing-in-Noise Test.

1. INTRODUCTION

Workplace noise is a major problem for many industrial and military work environments. In addition to permanent hearing loss, high noise levels can cause temporary loss of hearing and can compromise speech communication, sound localization, and warning sound detection, all of which can jeopardize worker and public safety.[1] Although the preferred method to minimize the adverse effects of workplace noise is through the use of engineering noise control and abatement measures, there are many instances where this is not technically possible, practical or economical, or does not reduce noise to safe levels.[1–3] Hearing protection devices (HPDs) have therefore played an important role in hearing conservation programs and are likely to continue into the foreseeable future.

The proper selection, fit and use of hearing protectors have been extensively studied[3] and are the object of national and international standards.[4–7] The attenuation provided by hearing protectors must be such that the resulting exposure is below the regulatory limit, typically an A-weighted level of 85 dB in most jurisdictions. Overprotection is not recommended, however, since workers may feel isolated from the surrounding environment, and it can deter proper communication, which is crucial for job efficiency and safety in the workplace. Accordingly, hearing protector standards, such as CSA Z94.2-02[4] and EN 458:2004,[5] recommend that the attenuation provided by HPDs be such that the protected noise level falls 5–10 dB below the regulatory limit for optimal device selection, taking into account hearing health and general communication needs.

The broad HPD selection guidelines above do not directly take into account the exact hearing status of the worker or the specific communication situation and auditory task at hand. Moreover, while current standards provide guidelines on the target protected noise level, it is well known that speech recognition depends on the spectral and temporal characteristics of the noise,[8–10] independently of global level. Giguere et al.,[9] for example, have found a range of 7 dB in the signal-to-noise ratio (SNR) required for normal-hearing subjects to reach 50% word intelligibility over a set of representative workplace noises from the Department of Fisheries and Oceans Canada. Rhebergen et al.[10] have found a range of 15 dB in the SNR required for 50% sentence intelligibility in normal-hearing subjects over a set of real-world steady and fluctuating background noises. Larger differences are expected for hearing-impaired individuals and when HPDs are worn. Hence, it remains difficult to ensure proper selection of hearing protectors in practice. Such difficulties are recognized in some standards. For example, EN 458:2004 recommends that tests be performed in the actual workplace in various noise conditions over a typical working day or week to verify proper audibility of signals and adequate ability to communicate by the individuals wearing the selected HPDs.[5]

The effects of HPDs on signal detection and speech perception depend on the complex interaction among several factors including attenuation, hearing loss, and the level, spectral and temporal characteristics of the noise and target signal. HPDs do not generally affect the perception of warning signals or speech, and they can even improve it for normal-hearing individuals in high-noise environments due to a release from perceptual distortion at loud speech and noise levels.[3] On the other hand, hearing protectors can compromise