1pNSa2. Advanced hearing protection and auditory awareness in individuals with hearing loss

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In-ear and earmuff-type electronic protection devices are rapidly being introduced into the marketplace and deployed in noisy industrial workplaces and military settings. In these environments, workers must be sufficiently protected from noise while being able to maintain good communication abilities and situational awareness. Features such as level-dependent attenuation or amplification, noise reduction, and remote communication capabilities are commonly found in advanced devices. The benefits of these features depend on their complex interaction with the signal and noise characteristics, the hearing status and language proficiency of the workers, and the nature of the auditory task. Furthermore, advanced devices often have different modes of operation and several user-adjustable control settings. In this paper, the interaction between the gain control setting and the degree of hearing loss is investigated for two level-dependent devices in a speech recognition task in noise. At all gain settings, the level-dependent mode of the devices provided better speech recognition that passive attenuation for all groups of subjects, and performance often exceeded unprotected listening.
INTRODUCTION

Noise is one of the most common problems in the workplace. In the USA, for example, approximately 22 million workers are exposed to daily hazardous occupational noise levels (Tak et al., 2009). In a sample of over 1.1 million American workers, 18% had hearing loss and prevalence ratios were especially high in mining, wood product manufacturing and construction of buildings (Masterson et al., 2012). Noise-induced hearing loss is also highly prevalent in the military. In the Canadian Forces, 42% of service members show at least a mild hearing loss and 26% develop a moderate to severe hearing loss by midlife, with some military trades such as infantry, artillery and flight engineers being the most at risk (Abel, 2005).

While engineering control at the source is the preferred noise mitigation method in hearing loss prevention programs, it is not always feasible to reduce noise to safe levels in some working environments or for some occupations. In these cases, supplementary methods such as the use of personal hearing protection become necessary. Conventional passive hearing protectors are commonly used and are often suitable when properly selected and fitted, but they may interfere with aural communication tasks and impede work performance and safety, especially in the presence of workers with hearing loss (Abel, 2008; Canetto, 2009; Casali, 2010; Giguère et al., 2010). For these individuals, the combined effect of hearing loss and hearing protection may be such that important sounds from the environment become inaudible.

Powered electronic hearing protectors are rapidly being introduced into the marketplace, often with the dual purpose of achieving protection against noise and enhancing situational awareness. In principle, workers with pre-existing hearing loss may particularly benefit from devices with level-dependent attenuation to maintain or enhance the audibility of signals at low and high levels. Advanced devices incorporating noise reduction technologies may also be useful to all workers. Unfortunately, the available research is rather limited on the benefits of powered electronic hearing protectors (Casali, 2010; Giguère et al., 2011a for reviews). Current devices often have different modes of operation and many user-adjustable settings and options, which complicate selection of the best solution for each particular situation. Moreover, information on many important electro-acoustic characteristics is not supplied by the manufacturers, which further compounds the problem.

In this paper, results from a speech recognition experiment conducted with two tactical communication devices are reported. The focus is on the interaction between the device settings and the subjects’ degree of hearing loss.

METHODS

Participants

Forty-five English-speaking adults (24 males, 21 females) participated in the study (mean age: 48 yr, standard deviation: 16 yr). Subjects covered a wide range of hearing profiles from normal hearing to severe hearing losses. Individual audiograms are illustrated in Figure 1.

![FIGURE 1. Bilateral hearing thresholds for the 45 subjects used in the study.](image)
Devices

Two tactical communication devices with level-dependent hearing protection were selected for the study: one earmuff-type device (Peltor® PowerCom Plus™) and one earplug-type device (Nacre QuietPro®).

The Peltor® PowerCom Plus™ is a circumaural device (Figure 2a) with built-in electronics that can be used for two-way radio communications as well as stereo surround listening (level-dependent). The user can manually select among five surround gain settings for active listening in the immediate environment. Electroacoustic testing of the device (Giguère et al., 2011b) shows that, at low levels (< 60 dBA), the insertion gain for frontal speech noise varies from about -6 to 13 dB across surround settings 1 to 5. At higher levels (> 60 dBA), the device shows gain compression which progressively reduces the transmitted sound to limit noise exposure. When the surround mode is deactivated (surround OFF), the device provides passive-only attenuation at a manufacturer rated NRR of 25 dB.

The Nacre QuietPro® is an in-ear device (Figure 2b) with built-in electronics and an external control unit that can be also used for two-way radio communications as well as stereo talk-through (i.e. surround) listening (level-dependent). The user can manually select among eleven talk-through gain settings. Electroacoustic testing of the device (Giguère et al., 2011b) shows that, at low levels (< 70 dBA), the insertion gain for frontal speech noise varies from about -12 to 12 dB across talk-through settings 2 to 11. At higher levels (> 70 dBA), the device shows gain compression which progressively reduces the transmitted sound to limit noise exposure. When the talk-through mode is deactivated (talk-through setting 1), the device provides passive attenuation at a manufacturer rated NRR of 29 dB. At very high levels, the device features active noise reduction (ANR), which provides an additional 6-8 dB of attenuation at low frequencies.

![FIGURE 2. Level-dependent communication devices used in the study: (a) Peltor® PowerCom Plus™ (b) Nacre QuietPro®.](image)

Experimental Protocol

Subjects were tested in a noise simulation facility in the Hearing Research Laboratory at the University of Ottawa. Two military noises recorded from light-armored vehicles in the Canadian Forces were used. Noise 1 (LAVIII vehicle) had a global Leq of 95.3 dBA and a spectral slope of -4.1 dB/octave. Noise 2 (Bison vehicle) had a global Leq of 89.5 dBA and a spectral slope of -2.6 dB/octave. Four-second samples were extracted from both noises for the listening experiments. The noise samples were presented over an array of loudspeakers around the subject to simulate a quasi-diffuse noise field. They were frequency-equalized and adjusted in overall level to match field recordings (Giguère et al., 2011b). The speech material was from the American English Hearing-In-Noise Test (HINT) (Vermiglio, 2008). Word recognition scores were collected from lists of 20 HINT sentences presented to the subjects from a frontal sound incidence.

Each subject was tested with only one of the two devices (22 subjects were assigned to the Peltor® PowerCom Plus™ and 23 subjects to the Nacre QuietPro®). Within each device, half of the subjects were tested in Noise 1 and the second half in Noise 2. Subjects were distributed to counterbalance hearing loss profiles across devices/noises.

Subjects were tested at two different signal-to-noise ratios (SNRs), individually selected to target word recognition scores in the 20-80% range unprotected, in each of the four listening conditions shown in Table 1.
TABLE 1. The four listening conditions used in the study. Each subject was tested at two SNRs per condition. The SNRs were fixed across conditions for a given subject, but varied across subjects. Surround # or TT # refers to the surround or talk-through level-dependent gain of the Peltor® PowerComPlus™ or Nacre QuietPro® respectively.

<table>
<thead>
<tr>
<th>Listening Condition</th>
<th>Comment</th>
</tr>
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<tbody>
<tr>
<td>No device</td>
<td>Unprotected</td>
</tr>
<tr>
<td>Device @ Surround OFF or TT 1</td>
<td>Passive protection (OFF)</td>
</tr>
<tr>
<td>Device @ Surround 1 or TT 4</td>
<td>Level-dependent (low gain = -4 dB)</td>
</tr>
<tr>
<td>Device @ Surround 4 or TT 10</td>
<td>Level-dependent (high gain = +10 dB)</td>
</tr>
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</table>

RESULTS

A very wide range of word recognition scores was obtained across subjects and device settings, from 0% to 96% correct. In Figure 3, the effect of three device configurations tested (passive protection, low gain setting, high gain setting) is shown for each device relative to unprotected performance. Negative/positive values indicate that the device degraded/improved speech perception performance compared to unprotected listening. The data is pooled into four hearing profile categories to illustrate the interaction between the device settings and the degree of hearing loss. The four hearing profile categories are normal hearing thresholds, slight-mild hearing loss, mild-moderate hearing loss, and moderate-severe hearing loss. There was little effect of noise type, and the data is averaged across the two noises in Figure 3.

Subjects in the normal-hearing category were largely unaffected when the level-dependent function of the devices was deactivated (surround OFF or TT 1), despite passive attenuation of 30 dB or more in this mode in the speech frequency range according to the manufacturers’ specifications. Normal-hearing subjects also showed improved speech recognition performance relative to unprotected listening when the level-dependent function of the devices was activated, by about 35% for the Peltor device in the two surround gain settings, and by 15% and 4% for the Nacre device at low and high talk-through gain settings, respectively.

Subjects in the hearing loss categories were negatively affected when the level-dependent function of the devices was deactivated (surround OFF or TT 1), by an amount dependent on the degree of the hearing loss. In the case of the Peltor device, speech recognition scores decreased by 32% for the slight-mild category up to 50% for the moderate-severe hearing loss category, relative to unprotected performance. For the Nacre device, speech recognition scores were lower by 19% to 42% relative to unprotected performance for the same subject categories. On the other hand, subjects with hearing loss greatly benefitted from the level-dependent function of the devices. At a low level-dependent gain setting (surround 1 or TT 4), a large increase in recognition scores was observed across compared to passive protection (surround OFF or TT 1), by 38-56% for the Peltor device and by 27-32% for the Nacre device across hearing loss categories. At the high level-dependent gain setting (surround 4 or TT 10), further improvements were observed for the mild-moderate and moderate-severe hearing loss categories with the Peltor device, and for the moderate-to-severe categories with the Nacre device.

FIGURE 3. Effect of level-dependent device setting (passive/off, low gain, high gain) on speech recognition in noise. Scores relative to unprotected performance. Data pooled into four hearing profiles. (a) Peltor® PowerCom Plus™ (b) Nacre QuietPro®.
Overall, the passive protection mode of the devices produced the largest variation in speech recognition performance relative to unprotected listening across subject categories (48% for the Peltor and 39% for the Nacre), while the high level-dependent gain setting showed the least variation across subject categories (16% for the Peltor and 5% for the Nacre).

DISCUSSION AND CONCLUSIONS

In contrast to conventional hearing protectors, advanced powered-electronic devices and tactical headsets can often be used over a wide range of user-adjustable settings and controls. However, few research reports or guidelines are available to identify the best settings for each user.

In this study, the interaction between the device settings and the degree of hearing loss was investigated for two level-dependent devices (Peltor® PowerCom Plus™ and Nacre QuietPro®) in a speech recognition task in noise. The subject pool covered hearing loss profiles from normal hearing to severe hearing losses. Given the wide range of speech recognition performance to be expected from such a heterogeneous population of subjects, testing was performed at a different set of SNRs for each subject to minimize floor and ceiling effects. Results were reported as the difference between word recognition score with the device fitted and the score without wearing the device at the same SNR, for two different SNRs. Thus, results express the effect of wearing the devices at different control settings with respect to the baseline unprotected listening condition for each given subject.

When the devices were used in a passive attenuation mode, by switching off the level-dependent surround/talk-through mode, subjects with normal hearing had speech recognition scores comparable to unprotected listening, but all subject categories involving hearing loss showed sizeable decrements in scores. For the moderate-to-severe category, the decrement reached 50% and 42% for the Peltor and Nacre devices respectively. Such outcomes found in the passive mode of the powered-electronic devices are in line with previous results on the effects of conventional hearing protectors and hearing profile under similar experimental conditions (Giguère et al., 2010). Clearly, as hearing loss progresses, significant drops in speech recognition in noise may occur with passive protection, likely due to loss of audibility.

When the devices were used with the level-dependent function activated (surround/talk-through mode), performance was markedly superior for all categories of subjects compared to the passive attenuation mode. Furthermore, speech recognition scores were as good (Nacre device) or better (Peltor) than unprotected performance from the normal hearing category up to the mild-moderate hearing loss category at both level-dependent gain settings (low, high), as well as for the moderate-severe hearing loss category at the highest gain setting tested (high). Large benefits are thus found with the level-dependent surround/talk-through mode of the devices. For subjects with normal hearing or hearing loss of up to about a mild-moderate degree, speech recognition performance in noise was relatively insensitive to the level-dependent gain setting (low or high). Subjects with more severe losses benefitted from using a high gain setting compared to a low gain setting, which likely further improved overall audibility. While not tested in this study, proper selection of the gain setting may nonetheless be an important factor to consider for all hearing-impaired users under conditions of low noise levels and distant talkers in order to compensate for elevated hearing thresholds.

Proper situational awareness in the noisy workplace is not only dependent on speech communication; it also involves a wider range of aural communication skills, including signal detection and sound localization (Abel et al., 2009; Casali et al., 2009; Giguère et al., 2012). Further work should continue to address all these dimensions in drawing up guidelines to obtain the best overall solution for each particular user given the task demands.

From a design standpoint, advanced hearing protection devices are increasingly incorporating sound processing functions and features typically found in hearing aids. Further integration of technologies can be expected and this holds promise for hearing-impaired individuals working in noisy environments to achieve both proper protection and good situational awareness. Measurement standards to specify all the relevant electro-acoustical characteristics of advanced hearing protection devices are currently lacking, though the advent of ANSI/ASA S12.42 should in part address this situation.

ACKNOWLEDGMENTS

REFERENCES


