Speech understanding in noise with integrated in-ear and muff-style hearing protection systems

Sharon M. Abel, Ann Nakashima, Douglas Saunders

Individual Behaviour and Performance Section, Defence Research and Development Canada-Toronto, Toronto, Ontario, Canada

Abstract

Integrated hearing protection systems are designed to enhance free field and radio communications during military operations while protecting against the damaging effects of high-level noise exposure. A study was conducted to compare the effect of increasing the radio volume on the intelligibility of speech over the radios of two candidate systems, in-ear and muff-style, in 85-dBA speech babble noise presented free field. Twenty normal-hearing, English-fluent subjects, half male and half female, were tested in same gender pairs. Alternating as talker and listener, their task was to discriminate consonant-vowel-consonant syllables that contrasted either the initial or final consonant. Percent correct consonant discrimination increased with increases in the radio volume. At the highest volume, subjects achieved 79% with the in-ear device but only 69% with the muff-style device, averaged across the gender of listener/talker pairs and consonant position. Although there was no main effect of gender, female listener/talkers showed a 10% advantage for the final consonant and male listener/talkers showed a 1% advantage for the initial consonant. These results indicate that normal hearing users can achieve reasonably high radio communication scores with integrated in-ear hearing protection in moderately high-level noise that provides both energetic and informational masking. The adequacy of the range of available radio volumes for users with hearing loss has yet to be determined.

Keywords: Communication, hearing conservation, noise exposure

Introduction

Military personnel are reluctant to wear conventional level-independent hearing protection devices during field operations. Although these devices reduce exposure to high-level sounds that could potentially damage hearing, they may interfere with the detection and localization of auditory warnings and the ability to understand and relay orders, putting the lives of the soldiers and completion of their mission at risk. This is especially the case for individuals who have already sustained a hearing loss. The sound attenuation provided by the device adds to elevated hearing thresholds, increasing the severity of the impairment. Level-dependent hearing protection devices may offer a solution. Passive nonelectronic types have a sharp-edged orifice or valve that allows low to moderate level noninjurious sounds to pass unimpeded. The attenuation is no more than 20 dB. High-level impulsive sounds, such as weapon’s fire, will create turbulence in the airflow surrounding the orifice, increasing the resistance and hence the sound attenuation. In contrast, active noise reduction (ANR) devices incorporate an electronic circuit which samples the ambient sound and adds it out of phase to the incoming waveform, thereby reducing the level of sound reaching the ear. ANR devices are designed for steady-state sounds below 1 kHz. The low-frequency attenuation that may be achieved varies widely across ANR devices but is typically no more than 20 dB. Higher frequencies are attenuated conventionally by about 35 dB.

The integrated hearing protection system, a relatively new development in hearing protection technology, offers a way to enhance free field and radio communications among soldiers in the field while at the same time protecting their hearing from the damaging and masking effects of high-level sounds. These may offer both ANR and protection against impulsive sounds. In a recently published study, Nakashima and Abel investigated speech understanding in 75-dBA pink noise in listener/talker pairs fitted with either of two in-ear integrated hearing protection systems, the Nacre QUIETPRO (Nacre AS, Trondheim, Norway) and the Silynx QuietOps (Silynx Communications Inc., Rockville, Maryland). These were compared with a Canadian Forces (CF) standard issue headset which offered no hearing protection. All three were used in combination with a Personal Role Radio (PRR; Marconi Selenia Communications, Genoa, Italy). Tests of
consonant discrimination and sentence intelligibility showed
that performance was best with the standard headset and radio
followed by the Nacre QUIETPRO and Silynx QuietOps.
Percent correct ranged from 70 to 89% for consonant
discrimination and 70 to 93% for intelligibility of words in
sentences. User acceptance was highest for the QUIETPRO,
followed closely by the standard headset.

The present study compared the effectiveness of increasing
the radio volume on radio communications in speech babble
noise with integrated in-ear and muff-style hearing protection
systems. Speech babble provides both informational and
ergetic masking. Energetic masking depends on the
spectral overlap and thus the speech-to-noise ratio (SNR) of
the speech and masking sounds. In informational masking,
the listener has to disentangle elements of the two that sound
similar. The candidate systems that were selected for
inclusion in this study were the Nacre QUIETPRO (Quietpro)
in-ear device and the Peltor PowerCom Plus (Powercom)
headset (3M, St. Paul, MN). Choice of in-ear or muff-style
hearing protection for use in military operations or industrial
settings will depend on how well they can be fit with other
head and face equipment, worn in combination.

**Experimental design**

Ten males and ten females of working age (military and/or
civilian) participated in the experiment. To control for the
effect of fluency on interpersonal communication in English,
all subjects were required to be proficient in speaking and
understanding unaccented North American English. While
accented speech may be intelligible in quiet, it is more difficult
to understand in background noise. Prior to inclusion in
the study, subjects were also screened for a history of ear
disease, including excess wax build up, hearing loss and
tinnitus, claustrophobia and difficulty concentrating over a
2-hour period, factors which could influence outcome. Those
who passed these screening criteria underwent a hearing test
conducted by a trained technician to ensure that pure-tone
air conduction thresholds were no greater than 20 dB HL
(decibels, hearing level) at sound frequencies from 0.5 to
8 kHz. This represents no more than a slight hearing loss.

Subjects were tested in same gender pairs in a sound-proof
room. Some studies have shown that speech spoken by
females is more intelligible than speech spoken by males,
although to a relatively small degree. Bradlow et al. reported
that intelligibility was positively correlated with
fine-grained acoustic-phonetic talker characteristics that
favored female talkers. In contrast, Nixon et al. found
relatively small gender differences favoring males at some
of the high levels of the aircraft background noises, in which
they presented their speech materials. They acknowledged
that this outcome may have been due to their military voice
communications system which was designed for the male
speech spectrum. Testing subjects in same gender pairs in
the present study avoided a potential confound that gender
differences might be due either to the gender of the speaker
or the listener.

Pair mates were fitted binaurally, in turn, with the Quietpro
earplugs and the Powercom headset. The order of the two
devices was counterbalanced across the 10 subject pairs.
In each of these two ear conditions, measurements were
made of the ability to understand radio communications
in a background of speech babble noise. The level of the
speech babble was adjusted to provide a safe at-ear value of
85 dBA. Based on pilot testing, this level was sufficient
to mask normal voice levels without the devices fitted,
ensuring that performance depended solely on the audibility
and clarity of the speech presented over the radios.
Measurements were made of the ability to discriminate
consonants presented at five radio volume settings which
included the minimum and maximum available for each
device. These were presented in randomized order,
determined for each pair, within device.

Members of each pair served in turn as the talker and listener.
One test of speech understanding, the Four Alternative
Auditory Feature Test (FAAF) was used. Subjects
were given a typewritten list of 80 sets of four common
monosyllabic words in the form of consonant-vowel-
consonants (CVCs). Half the sets contrasted the initial
and half the final consonant (e.g., wet, bet, get, yet or bad,
bag, bat, back). The order of these two types was random
throughout each list. Published studies have demonstrated
that initial consonants are significantly more distinctive than
final consonants. One word from each set, the designated
target, was spoken by the talker at a comfortable voice level
and the listener was required to circle the alternative heard
on an answer sheet. The target word was embedded in the
phrase “Can you hear…clearly”, spoken as a statement
rather than a question. Midway through the list, the pair
reversed roles. Five different lists were available. These were
counterbalanced across the 100 (2 × 5 × 10) possible device
by radio volume by subject pairs.

**Methods**

**Subjects**

The study protocol was approved in advance by the Human
Research Ethics Committee of our institution. Subjects were
recruited with the aid of an email sent to all employees. Those
who passed the screening criteria signed a Consent Form that
described the study prior to participating.

**Apparatus**

Pair mates were seated side by side at the center of a double-
wall, semi-reverberant sound proof booth (Series 1200,
IAC, Winchester, UK) with inner dimensions of 3.5 metres (L)
× 2.7 metres (W) × 2.3 metres (H) that met the requirements
for hearing protector testing specified in American National Standard S12.6-2008.[21] A room divider placed between them prevented visual contact. The ambient noise in the test facility was less than the maximum permissible for audiometric test rooms specified in American National Standard S3.1-1999 (R2008).[22] The speech babble noise was taken from the Speech Perception in Noise (SPIN) test.[23] Speech babble noise is commercially available on audio cassette (Auditec, Inc., St. Louis, MO). It was presented free field over a triad of loudspeakers (DL10, Celestion, Maidstone, Kent, UK) positioned near the corners of the room to create a uniform sound field.[24] The 85 dBA at-ear level of the speech spectrum noise was the same for pair mates.

The Quietpro and Powercom devices used in the study are battery-powered and can be used for two-way radio communications [Figure 1]. Both have OFF and ON modes of operation. According to the manufacturers’ specifications, in the OFF mode the Quietpro affords users passive (conventional) attenuation of the ambient sound of 24-42 dB from 0.125 to 8 kHz. The Powercom attenuates surround sounds similarly by 19-39 dB, in the same frequency range. When turned ON, both devices have a push-to-talk (PTT) feature for voice communications, and both allow for independent volume control of the surround and radio communications. When the Quietpro is in the ON mode, the ambient sound is maintained at a level no greater than 85 dBA. If the surround becomes too intense, talk through capability will be shut down, and active noise reduction (ANR) will be activated to provide a total attenuation (active plus passive) of 33-42 dB from 0.125 to 8 kHz. Intense impulsive sounds (e.g., from a gunshot or explosion) are compressed instantaneously. In the case of the Powercom, the surround must be turned off manually to protect hearing by the passive attenuation provided by the muff. The Quietpro requires connection to an external radio such as the CF standard issue personal role radio (PRR). The Powercom has a built in radio with a boom microphone for sending messages. For both devices, the subject hears the messages in the ear.

In order to obtain an at-ear level of 85 dBA for the present experiment, the speech babble was set at 75 dBA at source with the Quietpro surround feature set at the eighth of 11 possible levels and the Powercom surround feature set at the fifth of five possible levels. These selections were based on calibrations made using an acoustic test fixture.[25] The Quietpro has nine radio volume settings. Settings 1, 3, 5, 6 and 9 were tested. The Powercom has five radio volume settings. Settings 1, 2, 3, 4 and 5 were tested.

Procedure

Subjects participated in three experimental sessions. During the first session, pure tone thresholds were measured in each ear by a trained technician to ensure that the hearing screening criteria were met. They were then shown the two devices and given verbal instructions for fitting each before doing so themselves. Foam ear canal tips that attach to the transducer housing of the Quietpro [Figure 1a] are available in five sizes. The system conducts an automatic fit check to ensure that a good seal has been achieved. The Powercom is available in only one size. The headband is adjustable to allow for a good seal of the ear cups to the external ears. The fits of both devices were checked by a trained technician to ensure that they were well seated. This is a variation of Method A (Experimenter-Supervised Fit) described in ANSI Standard 12.6-2008.[21]
During the first session, subjects were also trained individually to use the PTT feature when performing as talkers. The Powercom was equipped with a PTT finger button [Figure 1c]. The PTT button on the Quietpro is located on the control unit [Figure 1a]. Subjects were instructed to pause for a count of five after depressing the button and again before releasing it, before and after the utterance, respectively, to avoid cutting off the beginning or ending. They paused for a count of 10 between presentations to allow the listener sufficient time to respond. The surround and radio volumes were set by the experimenter. Subjects were advised not to change the settings. For the Quietpro, subjects were also instructed not to adjust the volume of the PRR which was set to maximum.

Following the training session, subjects were scheduled to participate in two sessions on separate days to test each of the two devices, respectively. For these, they were paired with another subject of the same gender, randomly chosen by the experimenters. During each session, the FAAF lists were presented binaurally to the listener by the live voice of the talker over the radio of the communication device being tested. Listeners were encouraged to guess if uncertain as to the word that was presented. No feedback was given about the correctness of the responses. Subjects were given a brief rest after each list of 80 words had been presented, during which time the experimenter entered the booth and changed the volume of the radios. Throughout the experiment, communications were monitored by the experimenter seated outside the booth, using either a PRR radio in combination with a PRR headset for the Quietpro trials [Figure 1b] or a family radio service (FRS) walkie talkie for the Powercom trials. At the conclusion of the experiment subjects were invited to comment on what they liked and disliked about the two devices they had worn.

**Results**

The dataset for each of the 20 listeners consisted of the percentages (percent) of correctly identified initial and final consonants for the two devices (Quietpro and Powercom), at each of five radio volumes. The mean percent correct, averaged across listeners, was calculated for each of the ten combinations of device and radio volume, for the two consonant positions (initial vs final) taken separately. The outcomes are presented in Tables 1 and 2 for two types of group classification, gender (male vs female) and military status (civilian vs military), respectively. Previous studies have shown that female talkers may result in higher scores than male talkers in communication tests. The gender of the listener has not been found to be significant.

In the present study, both the listener and the talker were the same gender. Many of the military subjects had prior experience as radio operators, and thus were more experienced as listeners than the civilians, especially in noisy surroundings. There were an equal number of males and females in each of the civilian and military groups. However, while gender was a condition for the pairing of subjects, military status was not.

Thus a military listener might be paired with a civilian talker or the reverse.

The results displayed in Table 1 for the gender grouping indicate that for each device, the percent correct generally increased with increases in the radio volume over the range of settings investigated. Standard deviations for initial and final consonant positions at the minimum and maximum volumes for the two devices ranged widely from 8.1 to 27%. They were not systematically related to device, volume or gender. The median standard deviation was 17.6%, and 50% of the values fell between 11.5% and 19.7%. A repeated measures analysis of variance (ANOVA)\(^2\) was applied to the dataset to assess the effects of device, radio volume and consonant position, by gender. Since the range of radio volumes differed for the two devices, only the data for the minimum and maximum settings were included in this analysis. The ANOVA showed significant effects for device, radio volume, consonant position, and the interaction of consonant position and gender \((P<0.02 \text{ or better})\). The main effects are shown in Figure 2 and the interaction in Figure 3. The difference due to the device, averaged across the minimum and maximum radio volumes, consonant position and gender, was 8%,
with the Quietpro receiving the higher score of 70%. The effect of the increase in the radio volume, averaged across device, consonant position and gender, was 16% (74% for the maximum setting vs 58% for the minimum setting). Final consonants resulted in a 4% higher score than initial consonants (68% vs 64%). With respect to the interaction, the difference due to initial versus the final consonant position was only 1% for males (64% vs 63%, respectively) favoring the initial consonant but 10% for females (63% vs 73%, respectively), favoring the final consonant.

An ANOVA applied to the dataset for device, radio volume (minimum and maximum settings) and consonant position, by military status [Table 2] showed significant main effects of device and radio volume ($P<0.02$ or better). The observed differences due to these variables were the same as those observed for the ANOVA conducted for the gender groups. Military status was not significant nor were there any significant interactions. Consonant position was borderline significant ($P<0.054$). Averaged across device, minimum and maximum radio volumes and civilian and military groups, initial consonants resulted in a score of 64%, compared with 68% for the final consonant. The difference is similar to that observed for the gender ANOVA. Table 3 shows the median percent correct achieved by male and female listeners, in each of the military and civilian groups.

Medians were calculated in preference to means since there were only five subjects in each of the four gender by military status categories. These data show that, regardless of military status, device or radio volume, the median percent correct for the females was always relatively greater for the final than for the initial consonant. For males in the civilian subgroup, percent correct was relatively higher for the initial consonant, regardless of device or volume. For the male listeners in the military subgroup, a difference favoring the initial consonant was only evident for the Quietpro device at the lowest volume.

Eighteen of the 20 subjects commented on their experiences with the two devices tested. Responses obtained from males and females were similar. Regardless of the device, most subjects reported that the task became easier as the radio volume increased. However, a few noted that the difference in audibility was not appreciable for the Powercom. With respect to the Quietpro, most experienced discomfort when using the PTT button on the control unit. The button was difficult to see and to push, resulting in fatigue and soreness of the thumb by the end of the session. Five of the 18 subjects reported discomfort with the plugs. All preferred the finger PTT button used with the Powercom. It should be noted that a finger PTT is also available for the Quietpro.

It was not used in the present study because pilot subjects found it too cumbersome to hold the control unit and the

<table>
<thead>
<tr>
<th>Military status</th>
<th>Gender</th>
<th>N</th>
<th>Quietpro</th>
<th>Powercom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vol. 1</td>
<td>Vol. 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Civilian</td>
<td>M</td>
<td>5</td>
<td>56.0*</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5</td>
<td>78.0</td>
<td>82.0</td>
</tr>
<tr>
<td>Military</td>
<td>M</td>
<td>5</td>
<td>72.0</td>
<td>64.0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5</td>
<td>50.0</td>
<td>64.0</td>
</tr>
</tbody>
</table>

*Median value

---

**Figure 2:** Effect of device, radio volume and consonant position on consonant discrimination

**Figure 3:** Effect of gender and consonant position on consonant discrimination

---

**Table 3:** Discrimination of initial and final consonants with the Nacre QUIETPRO and Peltor PowerCom plus devices by males and females in civilian and military subgroups

<table>
<thead>
<tr>
<th>Military status</th>
<th>Gender</th>
<th>N</th>
<th>Quietpro Vol. 1</th>
<th>Quietpro Vol. 9</th>
<th>Powercom Vol. 1</th>
<th>Powercom Vol. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Civilian</td>
<td>M</td>
<td>5</td>
<td>56.0*</td>
<td>41.0</td>
<td>78.0</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5</td>
<td>78.0</td>
<td>82.0</td>
<td>78.0</td>
<td>86.0</td>
</tr>
<tr>
<td>Military</td>
<td>M</td>
<td>5</td>
<td>72.0</td>
<td>64.0</td>
<td>83.0</td>
<td>86.0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5</td>
<td>50.0</td>
<td>64.0</td>
<td>67.0</td>
<td>77.0</td>
</tr>
</tbody>
</table>

---

An ANOVA applied to the dataset for device, radio volume (minimum and maximum settings) and consonant position, by military status [Table 2] showed significant main effects of device and radio volume ($P<0.02$ or better). The observed differences due to these variables were the same as those observed for the ANOVA conducted for the gender groups. Military status was not significant nor were there any significant interactions. Consonant position was borderline significant ($P<0.054$). Averaged across device, minimum and maximum radio volumes and civilian and military groups, initial consonants resulted in a score of 64%, compared with 68% for the final consonant. The difference is similar to that observed for the gender ANOVA. Table 3 shows the median percent correct achieved by male and female listeners, in each of the military and civilian groups.
finger PTT, along with the clipboard and pencil required for responding. Five of the 18 subjects reported uncomfortable pressure of the Powercom muff on the ears or head.

Discussion

The experiment described above was designed to assess the effect of increasing the radio volume on the intelligibility of radio communications in moderately high-level speech babble noise for exemplars of in-ear and muff-style integrated hearing protection systems. Choice of these types for military operations or industrial settings will depend on requirements for use in combination with other head worn equipment. The results showed that radio volume affected the outcome significantly, although not significantly differently for the two devices. Averaged across the 20 subjects and consonant position, the highest mean score was observed for the highest volume setting, 79% for the Quietpro, compared with 69% for the Powercom. The mean score for the lowest volume setting was 61% for the Quietpro, compared with 55% for the Powercom. The difference between devices may be due to either differences in the range of at-ear radio volume levels or differences in clarity. Studies reported in the literature indicate that normal-hearing subjects can achieve 85% consonant discrimination for items mixed with speech spectrum noise presented over earphones at a speech-to-noise ratio of −4 dB.\(^{[27]}\) Speech-to-noise ratios could not be computed in the present study since changes in at-ear levels with changes in radio volume were not available for the two devices. However, the published data suggest that for the highest radio volume setting of the in-ear device the at-ear level would have had to be about 75-80 dBA. Gender of the listener (or talker since these were the same) was not a significant determinant of outcome as a main effect. This finding is in line with results reported by Nixon \textit{et al.}\(^{[17]}\)

Averaged across the two devices, minimum and maximum radio volumes, and gender, final consonants were significantly more easily recognized than initial consonants, although by a relatively small amount, 4%. However, statistical analysis also showed a significant gender by consonant interaction. Averaged across the two devices and the minimum and maximum radio volumes, females showed a 10% advantage for the final consonant, compared with 1% advantage for the initial consonants for the males. The mean scores obtained by males for the initial and final consonants and by the females for the initial consonant were similar at 63-64%, compared with 74% for the final consonant observed for the females. When the subjects were grouped by military versus civilian status of the listener, the group by consonant contrast interaction was only borderline statistically significant. Both groups showed relatively higher scores for the final consonant, with civilians at 3% and the military at 6%. This outcome was mainly due to the results for the female listeners (or talkers) in each group.

The observed benefit for final consonants in the present study is at odds with the previously reported finding of less difficulty perceiving changes in the initial consonant.\(^{[20]}\) In research by Redford and Diehl,\(^{[20]}\) CVCs were presented in a background of pink noise at an SNR of +15 dB to the open ears of male and female college students. The talkers were two males and two females. An initial consonant advantage was observed for all four talkers. By contrast, in the present study, subjects were listening to speech materials in a background of speech babble noise presented at a moderately high level over two different radios, each with its own unique acoustic properties. The observed final consonant advantage for the females may have been due to the spectral characteristics of the female talkers against the spectrum of the babble noise, which was presented at an adverse speech-to-noise ratio.

In summary, the results of this study showed that in moderately high levels of speech babble noise, and at the highest radio volume setting, subjects could achieve relatively high intelligibility scores with an in-ear integrated hearing protection communications device. However, one or other of the two styles of device tested might have a practical advantage depending on other head gear worn. For both the in-ear and muff-style devices, females proved to be either more understandable or better listeners than males, for final consonants. Previous research suggests that the gender of the talker rather than the listener is the more important variable.\(^{[16]}\) Drawbacks of the present study were that only subjects with normal hearing were tested and with relatively simple messages. Given the prevalence of noise-induced hearing loss among military personnel,\(^{[28]}\) the adequacy of the range of available radio volumes for users with hearing loss should be investigated, as well as message complexity.

Address for correspondence:

Dr. Sharon M. Abel,

Individual Behaviour and Performance Section,

Defence Research and Development Canada-Toronto,

1133 Sheppard Avenue West, Toronto,

Ontario, Canada M3K 2C9.

E-mail: sharon.abel@drdc-rddc.gc.ca

References


How to cite this article: Abel SM, Nakashima A, Saunders D. Speech understanding in noise with integrated in-ear and muff-style hearing protection systems. Noise Health 2011;13:378-84.

Source of Support: Defence R&D Canada, Personal Partner Group, Human Integration Thrust., Conflict of Interest: None declared.