Effects of hearing loss and language proficiency on speech intelligibility of radio messages over tactical communication devices

C. Giguère, C. Laroche, V. Vaillancourt

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Background – Noise in the military

- Military personnel face a wide range of noisy situations that can lead to temporary or permanent hearing loss
- Hearing abilities are key to maintain auditory situational awareness (Casali and Lee, 2018), which is imperative for safe and effective operations
  - Detection of footsteps
  - Localization of snipers
  - Speech understanding over radio communications
- Hearing protection equipment plays an important role for hearing loss prevention, but can compromise auditory situational awareness
- Tactical Communications and Protective Systems (TCAPS) aim to protect hearing while minimizing the impact on aural tasks (or even enhancing abilities)

Background – Hearing loss, fluency

- Effect of hearing loss
  - Decreased speech perception in noise with passive hearing protection
  - Level-dependent talk-through systems may help restore speech perception due to reduced attenuation or amplified transmission
- Effect of language fluency
  - Non-native talkers less intelligible than native talkers, especially in noise
  - Native listeners outperform non-fluent listeners in speech perception
    - Lower speech reception thresholds
    - Steeper growth functions relating intelligibility scores to signal-to-noise ratio
  - Effect is typically greater when non-fluents act as listeners than as talkers (related to use of contextual cues)
Rationale

- Effective radio communications are imperative to the success of defensive and offensive military operations.
- Important and rapid advancements in the design of TCAPS, but much research has been carried out with fluent normal or near-normal hearing individuals.
- Hearing loss and fluency issues in the military:
  - Noise-induced hearing loss more prevalent among military service personnel than in the general population
  - Non-native speakers among service personnel in countries with two official languages (e.g., Canada, Belgium)
  - Increase in multi-country deployments and operations where English is spoken as a second or third language
- Hearing loss and non-fluency can lead to reduced performance and efficacy, even miscommunications, particularly in high noise levels and when using TCAPS.

Objective and Study design

- To investigate the effects of hearing loss and language proficiency on the intelligibility and sound quality of radio messages over tactical communications devices.
  - Three groups (Control, Non-Fluent, Hearing loss) paired with a “standard” individual of the same gender
  - Live speech task over the radio channel
  - Two TCAPS models with integrated hearing protection
  - Two operational settings (talk-through ON and OFF)
  - One military noise

Methods – Participants

- 36 Group participants (18 F, 18 M) and 2 standard individuals (1 SF, 1 SM)
- Same gender pairs, each member acting in turn as talker and listener
- Results analyzed separately for Group participants acting as listeners and talkers

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristics</th>
<th>Standard Female – SF (NH and Fluent)</th>
<th>Standard Male – SM (NH and Fluent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>NH Fluent</td>
<td>6 females (F)</td>
<td>6 males (M)</td>
</tr>
<tr>
<td>Non-fluent</td>
<td>NH Non-Fluent</td>
<td>6 females (F)</td>
<td>6 males (M)</td>
</tr>
<tr>
<td>Hearing loss</td>
<td>Hearing-Impaired Fluent</td>
<td>6 females (F)</td>
<td>6 males (M)</td>
</tr>
</tbody>
</table>
Methods – Participants

Criteria for hearing status:
- NH: ≤ 15 dB HL (0.5-4kHz) & ≤ 25 dB HL (6-8kHz)
- Hearing loss:
  - Mild to moderate sensorineural loss, with 5-frequency PTA (0.5-4 kHz) between 25 and 55 dB HL in better ear
  - No asymmetry greater than 15 dB HL at 2 frequencies or 25 dB HL at one frequency

Criteria for fluency:
- Fluent in English:
  - Learning English before 11 years of age
  - Score of 36/40 or more on the Skylark Test of English Fluency (advanced level)
- Non-fluent in English:
  - Learning English after 11 years of age
  - Score of 28/40 or less on the Skylark Test (beginner to intermediate level)

Methods – Communications devices

Two TCAPS combined with Motorola two-way radio

- Threat4 X6200
  - External mic.
  - 5 talk-through levels
- Honeywell QuietPro400
  - In-ear mic.
  - 11 talk-through levels

Methods – Noise

Mixture of armoured vehicle noise (continuous) and battlefield noise (transient/impulsive) scaled to 85 dBA
Methods – Outcome measures

- Speech intelligibility – Modified Rhyme Test (MRT):
  - CVCs organized into 50 sets of 6 words differing only in the initial or final consonant
  - 6-alternative forced-choice in written format
  - Carrier phrase: “Mark the word ____ now”
    
    | MOS | Quality          | Impairment         |
    |-----|------------------|--------------------|
    | 5   | Excellent        | Imperceptible      |
    | 4   | Good             | Perceptible but not annoying |
    | 3   | Fair             | Slightly annoying  |
    | 2   | Poor             | Annoying           |
    | 1   | Bad              | Very annoying      |

- Quality of radio transmission – Mean Opinion Score (MOS):

Methods – Experimental protocol

- Practice items to set radio volume to optimal level
- For each experimental condition:
  - MRT list (50 items)
  - MOS
  - Radio volume settings used
- Total of 8 lists for each pair of participants:
  - 2 devices
  - 2 talk-through settings (OFF and ON at neutral gain)
  - 2 roles (talker and listener)

Results – Description of participants

- Skylark Test of English Fluency:
  - Standard Female (SF): 37 – Standard Male (SM): 39

![Skylark Test of English Fluency chart]

- Females
- Males

Group: Control, Non-fluent, Hearing loss
Results – Description of participants

- **Hearing thresholds**
  - Standard Female (SF) / Standard Male (SM): Normal Hearing
  - Control / Non-fluent Groups: Normal Hearing

![Hearing thresholds graph]

- **Hearing in Noise Test – Noise Front condition:**
  - Standard Female (SF): -4.1 dB SNR
  - Standard Male (SM): -3.7 dB SNR

![Hearing in Noise Test graph]

Results – MRT: Groups in listener role

- **Main effect of Group**
  - Control > non-fluent (8%)
  - Control > HLoss (trend only)

- **Interaction Device by Gender**
  - Threat > QuietPro in ON/OFF
  - by 18-28% across Group and Gender
  - No difference for talk-through ON vs OFF within device
  - Males > females
    - QuietPro OFF (10%)
    - QuietPro ON (trend)
    - Threat: No difference
**Results - MRT: Groups in talker role**

- **Main effect of Group**
  - Control > non-fluent (3%)
  - HLoss > non-fluent (5%)
  - Interacts with Device and Gender (trend)

- **Interaction Device by Gender**
  - Threat > QuietPro in ON/OFF
    - by 14% across Group and Gender
  - Talk-through setting:
    - Threat: OFF > ON for Males (4%)
    - QuietPro: No difference
  - Males > Females
    - Threat ON/OFF, QuietPro OFF
    - largest difference = 14%

**Discussion – Summary effects by factors**

- **Effect of fluency:**
  - Fluent listeners > non-fluent listeners (≈ 8%)
  - SF/SM did better when listening to fluent talkers (≈ 3-5%)
  - BUT, no apparent effect of fluency on MOS quality ratings or radio volume setting
    - No increase in radio volume for non-fluent listeners despite worse performance on screening HINT speech test
    - Speech task not limited by SNR, but rather limitations due to reduced language proficiency

- **Effect of Hearing Loss:**
  - Similar MRT scores for Hearing Loss and Control groups in listener role, but higher radio volume settings used by individuals with hearing loss
    - HL (at least mild/moderate in degree) can be compensated for by increasing speech level or SNR = importance of user-adjustments
    - Noted tendency for SF/SM to speak louder to Hearing Loss group
  - No effect of hearing loss in talker role


Discussion – Summary effects by factors

- **Effect of Device:**
  - Important between-device effects (Threat > QuietPro)
    - By 18-28% in listener role and 14% in talker role
    - QuietPro: lower MOS speech quality ratings and higher radio volume used
    - High-frequency response limitations associated with ear canal microphone?
  - Similar performance and radio volume used in both talk-through modes (ON/OFF)
    - No interference of external background noise or talker compensation for noise through Lombard effect

- **Effect of gender:**
  - Males > females when using QuietPro, but similar quality ratings and radio volume settings
    - Again could be attributable to reduced high frequency response with an ear canal microphone? Negative impact of transmission of female voices.
    - Noted tendency for some males to talk louder in noise than females, especially with the non-fluent group.

Conclusions

- Hearing loss found to have lesser impact than fluency
  - Can be offset by higher radio volume (↑ audibility and SNR)
    - Could be further improved by technical features like individualized gain-frequency functions
  - Fluency effects are harder to compensate for technologically (other forms of communication may at times be more suitable, e.g., texting, visual displays)

- Tradeoff between external vs in-ear microphones
  - Limited intrusion of background noise by in-ear mics but reduced sensitivity to high-frequency speech content
    - May be more critical with female talkers

- No large effects of talk-through mode (ON vs OFF)
  - Talk-through may be preferred when both situational awareness and radio communications are critical
### Conclusions

**Limitations and/or future work:**

- Limited number of participants in each group
- Investigation of special features to compensate for hearing loss such as individualized gain-frequency functions
- Effect of information overload or divided attention issues when tasks combine talk-through and radio transmissions
- Combined effects of hearing loss and reduced fluency
  - Realistic outcome for older and noise-exposed military personnel in bilingual countries such as Canada and in multi-country operations
- Effect of contextual information in interaction with hearing loss and fluency
  - Investigation with different speech material, for example high vs low-predictability sentences
  - Initial/final consonant discrimination task in MRT may be less sensitive to differences in fluency

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#### but can still be crucial to speech understanding

[https://www.youtube.com/watch?v=0MUsVcYhERY](https://www.youtube.com/watch?v=0MUsVcYhERY)