SPEECH-IN-NOISE RESEARCH: FROM CIVILIAN TO MILITARY OPERATIONAL ENVIRONMENTS

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Résumé

L'importance de l'intelligibilité de la parole dans les environnements d'apprentissage et de travail est soulignée par l'abondance de recherches effectuées sur l'acoustique des salles et sur la communication auditive. En plus des facteurs environnementaux tels que le bruit de fond et la réverbération, il est également nécessaire de prendre en considération les facteurs individuels, tels que la perte d'audition, le port d'appareils auditifs et de dispositifs de protection de l'ouïe, ou encore les compétences linguistiques. Les études antérieures dans ces domaines ont fourni une base de connaissance pour l'étude de la communication dans les environnements complexes très bruyants. Pour les membres de Forces armées canadiennes, les hauts niveaux de bruit dans les aéronefs, les véhicules blindés et les navires militaires exigent l'utilisation de protecteurs auditifs et de systèmes de communication. Dans cet article, nous examinons certains des défis associés à la communication dans les environnements opérationnels et comment les tests de parole dans le bruit sont adaptés au contexte militaire. Les similitudes et les différences entre la recherche portant sur la communication auditive dans les salles de classes, les environnements civils et militaires sont également abordés.

Mots clefs : bruit militaire, communication auditive

Abstract

The importance of speech intelligibility in learning and occupational environments is evidenced by the abundance of research in room acoustics and auditory communication. In addition to environmental factors such as background noise and reverberation, individual factors including the presence of hearing loss, wearing of hearing aids and hearing protection devices (HPDs) and language proficiency must be considered. Previous work in these areas has provided a foundation for the study of communication in complex, high noise environments. For Canadian Armed Forces (CAF) members, the high noise levels inside aircraft, armoured vehicles and sea vessels demand the use of HPDs and integrated radio communication systems. In this paper, we review some of the challenges associated with speech communication in military operational environments and how speech-in-noise testing is adapted for military relevance. Similarities and differences amongst auditory communication research in classrooms, occupational and military environments will be discussed.

Keywords: military noise, auditory communication

1 Introduction

Noisy environments are inherently difficult for speech communication. In searching the literature for strategies to deal with speech communication in noise, there is a large body of research on speech in classrooms. Noise levels and their impact on students and teachers have been studied in a full range of educational levels from pre-school to university [1-3]. In addition to causing communication problems, noise adversely affects the recall of text and word comprehension [4], which has a negative impact on learning. Classroom noise also has adverse health effects on teachers relating to hearing loss and mental health [2] and voice problems [5]. Typical solutions that are recommended for classrooms are to decrease the room volume and/or add sound-absorptive materials, which have the effect of reducing the reverberation time and the speech-to-noise ratio (SNR) in the room [6]. Since the proximity of students (listeners) relative to the noise sources is also relevant, listeners and workstations should be moved away from noise sources such as heating, ventilation and air conditioning (HVAC) outlets.

In many occupational settings, it is not possible to change the environment or move away from noise sources, yet speech communication is critical to job function. In a comprehensive summary of hearing-critical tasks and noise environments of law enforcement and public safety workers, it was concluded that the primary functional hearing ability was speech communication, while the primary interfering factor was noise [7]. It was found that in most of the environments, the likelihood of effective speech communication was less than 0.5 for normal voice levels, and communication at distances greater than 5m was unlikely [7]. In high-noise environments, effective communication can only be achieved through the use of communication headsets.

Even in environments that are acoustically well-designed for speech, or when communication headsets are

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used, individual factors play a significant role in effective communication. Listeners with hearing impairment (HI) have more difficulty with speech understanding in low SNR and higher reverberation conditions than those with normal hearing [8]. Industrial workers with hearing loss worry about safety and job performance, including the ability to communicate [9]. Non-native (L2) listeners are also at a disadvantage compared to native (L1) listeners for speech understanding in unfavourable acoustical conditions, which is possibly exacerbated by increased cognitive effort [10]. Recent work has shown encouraging progress in predicting the likelihood of effective speech communication for normal hearing and HI individuals [11], but to the author's knowledge, there is no analogous metric for non-native speakers.

Can the results of previous work on speech communication in classroom and occupational environments be applied in the study of military operational environments? In terms of the noise environment, there is little room to improve the acoustic conditions in military vehicles. In the tight confines of an aircraft cockpit, armoured vehicle or frigate control room, there is no space to move operators away from HVAC outlets and other noise sources. Hard, reflective surfaces and walls inside vehicles further elevate the noise levels. The issue of HI-speech understanding is critical since noise-induced hearing loss is common in military operators (MOs) [12]. Foreign accent and L2 listeners can adversely affect communication effectiveness, particularly in multi-national operations. This is a topic of a current North Atlantic Treaty Organization (NATO) Human Factors and Medicine working group (HFM-285). Although MOs anecdotally report fatigue from noise exposure, other operational stressors such as vibration are often present. These confounding factors make it difficult to attribute non-auditory performance decrements to noise exposure alone. Therefore, the acute and long-term cognitive and mental health effects of military noise exposure are not well-understood.

This paper discusses 1) the challenges for speech communication in military environments, 2) how speech-in noise testing is adapted for relevance to military settings, and 3) the common elements of speech communication in educational, occupational and military environments and future work.

2 Speech in military noise environments

2.1 Military noise levels

Sample noise levels that have been measured in Canadian Armed Forces (CAF) operational environments are shown in Table 1. At the lower end of the scale, frigate control rooms can be about 60 dBA during quiet watch, but can rise above 70 dBA during periods of high activity due to more occupants and more talking (louder voices) in the room [13]. Armoured vehicle noise levels range from 70 dBA while idling to as high as 115 dBA when moving at highway speeds with the hatches down [14]. Reported cockpit noise levels in military aircraft range from 95 to 105 dB [15], while one study of an RCAF Chinook helicopter reported cabin noise levels as high as 113 dBA with the door open [16]. Finally, MOs are exposed to high levels of impulse noise from weapons. Small arms fire has been measured at around 150 to 170 dB peak at shooting ranges [17] while artillery noise can exceed 180 dB peak [18]. Given these ambient noise levels, unaided speech communication would only be possible in frigate control rooms. Communication headsets are required in most military operational environments.

Table 1: Sample noise levels in CAF environments.

Environment	Average or range of noise levels
[13]Frigate (bridge)	62 – 70 dBA
[13]Frigate (operations room)	65 – 75 dBA
[14]Armoured vehicles	70 – 115 dBA
[15,16]Aircraft	95 – 113 dBA
[17]Rifle shooting range	150 – 170 dB peak

2.2 Auditory workload

MOs often experience high auditory workload, owing to high ambient noise, face-to-face conversations and traffic from multiple radio networks. A recent communication study on a Canadian Patrol Frigate identified 25 different shipboard voice networks, with the operators concurrently monitoring 2.5 networks on average, in addition to face-to-face interactions with their collaborators. Of the factors that negatively influenced communication effectiveness, noise was most frequently reported, followed by the need to talk to multiple people or monitor multiple networks concurrently. Level-dependent earplugs were suggested for MOs who communicate face-to-face in moderate levels of noise, in order to facilitate communication while reducing noise annoyance [19]. Adding a visual element to an auditory message, e.g., text on the screen, can be helpful in improving the accuracy of coding messages correctly [20, 21]. Unfortunately, these strategies can be difficult to implement in command posts where the MOs are already monitoring multiple screens.

2.3 Hearing thresholds

The CAF Medical Standards document categorizes hearing ability of MOs from H1 (best) to H4 (worst) based on pure-tone audiometric thresholds as shown in Table 2 [22]. All Military Occupational Structure Identifications (MOSIDs) require hearing H3 or better, with some requiring H2 [22]. Importantly, the requirements for H2 and H3 are outside of the limits for normal hearing [23], and it is recognized that CAF members in these hearing categories typically have significant high-frequency hearing loss. Such hearing impairment could be a substantial barrier to speech communication in operations. A previous focus group study found that MOs would rely on younger members, presumably with better hearing, for confirmation of commands [24]. Although MOs believed that the use of hearing protection devices (HPDs) could reduce hearing loss, their use was inconsistent in practice [24]. The hearing ability of MOs and use of HPDs must be considered when designing studies of speech understanding in noise.

Table 2: CAF hearing categories [22].

Category	Required Hearing Level
H1	≤ 30 dB HL from 500 to 8000 Hz, both ears
H2	≤ 30 dB HL from 500 to 3000 Hz, both ears
H3	≤ 50 dB from 500 to 3000 Hz, either ear
H4	> 50 dB from 500 to 3000 Hz, either ear

3 Speech-in-noise tests for military

3.1 Choosing a test

One reason for using speech-in-noise tests is to assess an individual's functional hearing for their job, which has also been called auditory fitness for duty (AFFD). Assessment of speech understanding in noise is particularly important if a hearing loss is indicated on the audiogram. In the United States, Army members with H3 hearing are tested using the speech recognition in noise test (SPRINT) [25]. It is noted that H3 for the US Army is described as "speech reception threshold in best ear not greater than 30 dB HL, measured with or without hearing aid [26]," which is different from the CAF definition shown in Table 2. The SPRINT uses pre-recorded monosyllabic words in multi-talker speech babble, and has recently been implemented in a shortened form to improve efficiency for clinical use [25]. However, its use in future functional hearing assessment is unlikely due to its open set response (verbal response that is marked subjectively), which cannot be automated [25]. A possible alternative is the matrix test, which uses sentences comprised from a closed set of words from fixed categories. It is an automated test that has been implemented in many different languages, making it accessible for international use [27].

For the CAF, it is critically important to have equivalent tests in English and French. The hearing in noise test (HINT) has been adapted for Canadian Francophone populations, and it has been used successfully for personnel in police, coast guard and other public safety services [28]. Possible drawbacks for widespread use of the HINT across the CAF are the required clinical setup and administration time. The Canadian Digits Triplet Test (CDTT) is potentially very useful because it is bilingual, can be administered quickly, and does not require an audiometric booth [29]. Previous research has shown that the Digit Triplet Test in other languages is sensitive to high-frequency hearing loss [30], which could be useful as an early indicator of hearing loss.

The coordinate response measure (CRM) is a speech corpus of phrases consisting of a call sign, colour and number (e.g, "Ready baron, go to blue five now") [31]. The CRM has been implemented for research in multi-talker environments. This is useful for studying speech understanding in noise with multi-channel communication headsets, which is discussed in the next section.

3.2 Speech understanding with hearing protection and communication headsets

Aside from evaluating the unaided, unoccluded functional hearing of an MO, another question is whether or not an acceptable level of performance can be achieved when using a particular HPD or communication headset. While people tend to raise their voices in noise (Lombard effect), perception of own voice is different when wearing a HPD; the occlusion effect causes differences in speech level production and fundamental vocal frequency [32]. Therefore, the speech-to-noise ratio (SNR) that is required at the listener's ear might be different when wearing an HPD or headset compared to unoccluded. When using communication headsets, users are able to adjust the volume to their preferred level. In environments with lower background noise, such as frigate control rooms (see Table 1), it is possible and necessary to have face-to-face communication within the room. However, when the MOs are not co-located or the background noise levels are too high, noise-reducing communication headsets must be worn. While communication headsets facilitate speech understanding by feeding the radio channel directly to the ear, the additional contribution from the radio must be considered for consideration of noise exposure. A previous study of communication headset use in occupational settings found that users adjusted the radio volume at an average effective SNR of 13.7 dB, after accounting for the attenuation of the headset [33].

When considering speech understanding with communication headsets, it is reasonable to look to a standard for guidance. The American National Standards Institute/Acoustical Society of America (ANSI/ASA) S3.2, Method for Measuring the Intelligibility of Speech over Communication Systems allows for three sets of test material: phonetically balanced word lists, the modified rhyme test, the diagnostic rhyme test. It states that test participants must be audiometrically normal, with required hearing levels of ≤ 20 dB HL from 125 to 8000 Hz. As discussed in Section 2.3, many CAF members would not meet this hearing requirement. In addition, for complex listening environments, such as monitoring multiple radio networks in a command post, simple word recognition might not be a good indicator of ability. The CRM has been implemented in diotic and dichotic listening conditions where the participant was required to respond by pressing the correct key sequence (e.g., blue, five) rather than repeat what was heard [20, 21]. Distractor tasks and audio-visual presentation of the command were also used. It was found that visual cues help [20] and there was a slight advantage for messages presented to the right ear [21].

While the CRM studies mentioned above looked at performance as the percentage of correct responses, performance is also measured by determining the SNR at which 50% of the words are correctly identified; this is called the speech-reception threshold (SRT). Since performance on speech-in-noise tests depends highly on the choice of speech material and type of noise, it is useful to compare the relative SRT of HI, L2 listeners to normal-hearing, L1 listeners for a given test. A previous study found that listeners with varying levels of HI required SRTs of 4 to 10 dB higher than normal-hearing listeners across different speech-in-noise tests [35]. It has also been reported that non-native speakers, even if fluently bilingual, require higher SRTs than native speakers [36], and obtain lower scores on fixed SNR tests [37]. HI and L2 listeners have greater difficulty with speech understanding while wearing HPDs than normal-hearing listeners and L1 listeners [38-40].

3.3 Interference caused by personal protective equipment

Since environmental hazards for military personnel are not limited to noise, HPDs are often worn in combination with other types of personal protective equipment (PPE). Flight helmets are typically designed for HPDs because of the integrated communication requirement. For other types of helmets, HPDs are designed to be mounted on them. Such integrated PPE combinations are easily tested. However, other types of PPE might not be designed for optimal hearing protection and communication. Balaclavas that would be worn in cold environments have been shown to reduce the attenuation of an earmuff worn in combination. Although consonant perception in quiet was not affected by the balaclava, speech-in-noise and sentences were not tested [41]. Reduced speech understanding has been shown for respirators and safety glasses that are worn in toxic environments [42].

3.4 Beyond speech-in-noise tests

There are other aspects of situational awareness aside from speech communication that are critical to the effectiveness and survival of MOs. Detection, recognition and localization of sounds, especially warning sounds, are important aspects of functional hearing [43]. While outside the scope of this paper, recent work on AFFD is well described elsewhere [7, 11, 44].

4 From civilian to military operational settings

On the surface, there appear to be few similarities for speech communication in classrooms, civilian occupational and military environments. Although the environments, noise levels and auditory tasks are different, the common element is the human. Whether conducting research for face-to-face or radio headset communication, the human factors that have been considered across these environments include:

- HI talkers and listeners;
- L2 talkers and listeners;
- Noise interference (background noise, competing talkers);
- Cognitive effort.

Research on HI-participants in classrooms includes hearing aid and cochlear implant users, which is different from military populations with noise-induced hearing loss (NIHL). Similarly, AFFD with hearing aids for civilian occupations [45] is not relevant to MOs who work in noisy environments, where the use of hearing aids is contraindicated due to interference with HPDs. However, the non-native communication literature is much larger for classroom and civilian settings than for military environments. Previous work suggests that cognitive load could be especially high for L2 speakers who learned after early childhood [46], which is likely more typical for MOs. Training and other methods to improve L2 speech understanding in noise should be investigated further.

To the author's knowledge, listening effort and the associated cognitive load have not been thoroughly investigated in military operational settings. Effortful listening is described as "the deliberate allocations of mental resources to overcome obstacles in goal pursuit when carrying out a (listening) task" [47]. A recent paper has provided a framework for understanding effortful listening (FUEL), which could be useful in designing studies for complex environments [47]. Listening effort has been previously measured through dual-task paradigms [48] and more recently through pupillometry [49].

5 Conclusion

The typical solutions for improving speech understanding in noise cannot all be transferred from civilian to military settings. In particular, it is not feasible to fix the acoustical environment or gain distance from noise sources in order to improve communication effectiveness. However, the use of modern communication headsets and adaptation of speech-in-noise tests have enabled progress in the military context. To better understand the individual factors that affect communication, further research on HI and L2 speech understanding, and their relationship with cognitive effort, will benefit workers in all environments.

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