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Using the Callsign Acquisition Test (CAT) to investigate the impact of background noise, gender, and bone vibrator location on the intelligibility of bone-conducted speech

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ABSTRACT

Traditionally, combat operations have relied on air-conducted radio communication to receive and transmit information. Recently, however, there has been the need to find alternatives because headphones used in air conduction are bulky and cover the ears of the listener, thus reducing the listener's awareness of his/her surroundings. Bone-conducted radio communication, however, uses lightweight and inconspicuous transducers which allow radio communication without compromising the listener's awareness of his/her surroundings. This research investigated the intelligibility of bone-conducted speech in white, pink, babble and quiet background environments at the condyle and mastoid locations on the head using the Callsign Acquisition Test (CAT). Data were collected and analyzed from 20 normal hearing participants (10 males and 10 females) between the ages of 19 and 31 years. Significant interaction effect between gender and background noise was found from the results. Post-hoc analysis showed that for both males and females, background noise had a significant impact on speech intelligibility. In babble background, there was a significant difference in speech intelligibility between the male and female listeners (males performed better than females). However, no significant effects were found for the other type of background noises. The results also indicated that there was no statistically significant difference in intelligibility scores between the condyle and mastoid locations.

Relevance to industry: This study investigated the impact of background noise, gender of listener, and location of bone vibrator on the intelligibility of bone-conducted speech. Findings of this study revealed the impact of different background environments and listener's gender on speech intelligibility and will assist in the development of improved bone conduction devices in the future.

1. Introduction

The soldiers' survival on the battlefield depends to a large extent, on their ability to hear and understand communicated speech clearly. In other words, soldiers need to be able to hear and understand radio messages clearly, receive verbal orders and communicate with other members of their infantry (Rao and Letowski, 2003). The success of any tactical military operation depends heavily on efficient and timely radio communication. Delivering the right information to soldiers at the right time and in a form that is clear can mean the difference between life and death for these brave soldiers.

Consider this scenario where a field commander and his/her troops come under surprise enemy fire. The field commander asks for air support from command and control to neutralize the enemy fire. He is asked to provide the location of the suspected enemy but instead furnishes command and control of his own location because of low speech intelligibility. A short time later, the commander and his/her troops are under intense air bombardment. If the communication from command and control had been intelligible enough, the commander would have provided the location of the enemy instead of his/her own. In light of the above, it can be argued that unintelligible speech is worthless, but low intelligible speech can be worse. It is also worth mentioning that, a speech unit that is loud enough to be heard or audible is not necessarily intelligible. This is because though the speech may be audible, it may also be overly reverberant or distorted in some way, making it unintelligible and therefore useless (Letowski, 2002).

The purpose of this study was to use the CAT to investigate the impact of background noise, gender of listener, and vibrator location on the intelligibility of bone-conducted speech.

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1.1. Air and bone conduction

Generally, there are two alternate means by which radio communication can be transmitted: air conduction and bone conduction. Air conduction is the natural process by which sound waves are collected by the outer ear and transmitted through the ear canal to the inner ear for processing. Bone conduction, on the other hand, is the mechanical process by which sounds are transmitted from the cranial bones of the head to the inner ear without passing through the ear canal (Studebaker, 1962).

Traditionally, air conduction is more commonly used in industry; however, bone conduction radio communication offers an attractive means for infantry to communicate on the battlefield because it enables auditory signals to be transmitted and received without compromising the soldier's awareness of his or her surroundings. With bone conduction, soldiers can receive and transmit radio communication while maintaining full awareness of the noisy, dangerous and often unpredictable environment of military warfare, and yet maintain portability and privacy. Bone conduction interfaces are also lighter and smaller than earphones and can easily be integrated into military headgear. Developing efficient and reliable bone conduction interface for use in the battlefield will lead to improved situation awareness and enhance the intelligibility of communicated speech.

In bone conduction, the sound waves can be transmitted through vibrations from the skull of the talker to a contact microphone and from a bone vibrator to the skull of the listener (McBride et al., 2005). There are several ways through which hearing by bone conduction can be achieved. The most common method is to place a bone vibrator on the skin covering the skull or by surgically attaching the bone vibrator to the skull such as in bone anchored hearing aids. Hearing by bone conduction can also occur naturally when exposed to loud background or ambient noises which stimulate the cranial bones or when listening to one's own voice (Gripper et al., 2007).

1.2. The impact of gender on speech intelligibility

Although there have been some studies to investigate the impact of gender on speech intelligibility, there is no unanimous consensus on what impact gender really has on intelligibility. Stevens et al. (2005) reported that gender of speaker and the quality of signal affect intelligibility, and that generally the male voice is more intelligible than the female voice. Kelic and Ogut (2004) concluded that female speech is significantly more difficult to discriminate than male speech in normal hearing subjects when noise is present and Cerrato (1995) reported that female speakers tend to be more intelligible than male speakers. From the listener's perspective, Ellis et al. (1996) found no significant difference between male and female listeners' intelligibility scores; however, their overall impression of the intelligibility of the speaker tended to differ. While female listeners indicated that they found male voice more intelligible, male listeners indicated that they found the female voice more intelligible. Wilding and Cook (2000) reported that while males showed no differentiable ability to recognize male over female voices, females showed an enhanced ability to recognize female voices as well as being more accurate overall.

1.3. Speech intelligibility

Speech intelligibility is the percentage of speech units that can be correctly identified by a listener over a given communication system in a given acoustic environment or the degree to which speech can be understood within a given acoustic environment (Letowski et al., 2001). Put differently, it is the degree to which a speaker's intended message is recovered by a listener. Reduced speech intelligibility severely compromises communication and social interaction for affected individuals. Several factors influence speech intelligibility. These include background noise, distortions, reverberations and frequency among others; however, background noise is usually the most important factor to consider. The effectiveness of a communication system or of the ability of people to communicate in noisy environments can be measured by performing speech intelligibility testing.

Speech intelligibility can be measured directly or indirectly. In a direct measurement, a number of talkers will speak words or sentences and a number of listeners will indicate what they hear. However, tape recordings of the speakers are often used rather than live speech, so that different communication systems can be compared with exactly the same speech material (Lower, 1997). In indirect testing, either a speech or a special test signal is broadcast over the system, and the received signal is picked up by a microphone and analyzed to produce the signal and degradation components. A ratio of useful signal to noise signal is computed.

Traditional speech intelligibility tests include the Modified Rhyme Test (MRT), Diagnostic Rhyme Test (DRT), Northwestern University Test number 6 (NU-6), Diagnostic Medial Consonant Test (DMCT) and Central Institute for the Deaf Test (W-22) among others. However, these tests have been criticized for having poor validity in military settings (Blue, 2002). One likely reason for poor performance on these tests in military applications is because most of the tests were developed primarily for clinical diagnostic testing. To address this shortfall, the Callsign Acquisition Test (CAT) was developed.

1.4. Callsign Acquisition Test (CAT)

In response to the criticism of MRT and the other clinical speech tests that have been described above, the Callsign Acquisition Test (CAT) was developed by the Auditory Research Team (ART) of the Army Research Laboratory Human Research and Engineering Directorate (ARL–HRED) specifically for military applications. It consists of 18 two-syllable military code words and seven one-syllable digits. In all, there are 126 items in CAT. The CAT words were derived from NATO and the International Civil Aviation Organization standard word list. However, only the two-syllable words in the list were selected for CAT. The digits are the one-syllable digits from one to eight, except seven which is two-syllable. The CAT uses military code words familiar to soldiers and therefore has greater appeal among military personnel (Blue et al., 2004). Soldiers are therefore more likely to respond correctly when these speech materials are presented. For this reason, the CAT was used as the speech testing material in this research.

2. Methodology

In this research, the condyle (the bony protrusion in front of the ear) and mastoid (the protrusion of the temporal bone behind the ear at the base of the skull) were selected as the bone vibrator placement locations. The selection of the condyle and mastoid for this research was based on the previous study by the authors (Osafo-Yeboah et al., 2006) who investigated the most favorable locations on the head for optimum bone vibrator placement and found the condyle and mastoid as the most favorable locations. Another study conducted by McBride et al. (2005) investigated the sensitivity at 11 bone vibrator locations on the head using pure-tone signals and found the condyle and mastoid were the most favorable and second most favorable locations, respectively, for bone vibrator placement.

Another reason is that both the condyle and the mastoid are close to the ear, and therefore, it is possible for the ear to collect residual sound waves that might leak from the bone vibrator that is