International Journal of Industrial Ergonomics 38 (2008) 1038–1044

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Speech intelligibility differences of male and female vocal signals transmitted through bone conduction in background noise: Implications for voice communication headset design

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ARTICLE INFO

Article history:
Received 25 May 2007
Received in revised form
25 March 2008
Accepted 27 March 2008
Available online 19 May 2008

Keywords:
Bone conduction
Speech intelligibility
Communication devices
Modified rhyme test

ABSTRACT

Tactical organizations require verbal communication that is clear and intelligible. When designing new devices, communication equipment developers must not only consider the electrical components of the devices but also various parameters of both the listening environment and signals being transmitted. Bone conduction communication devices have recently been introduced into several tactical organizations; however, the effectiveness of these devices has not been comprehensively explored. This paper describes a study investigating the impact of voice type (male and female), location (condyle and mastoid), and background noise level (0, 83, 93, and 103 dB(A)) on the intelligibility of bone-conducted verbal communication. Results of the study indicated the male voice tested outperformed the female voice within each noise level except for the 0 dB(A) noise level. At the 0 dB(A) noise level, the female voice outperformed the male voice. There were no performance differences found between locations at the 0 or 83 dB(A) noise levels; however, at the 93 and 103 dB(A) noise levels the condyle outperformed the mastoid.

Relevance to industry

Various agencies are currently utilizing bone conduction communication devices in tactical missions. Due to the critical nature of these missions, it is important to determine conditions in which bone conduction communication devices are most (and least) effective in order to enhance present and future designs.

1. Introduction

Clear and intelligible radio communication is an essential component to successful completion of tactical missions. This is especially relevant in organizations such as military, fire fighting, and law enforcement agencies. In these particular fields, unintelligible verbal communication can often be even more detrimental than inaudible signals, such as in the case where a signal is heard but misinterpreted causing the receiver to take actions which result in capture or even death (Gripper, 2006).

One particular form of technology believed to be capable of enhancing communication during tactical maneuvers is the bone conduction device. These devices have certain advantages over traditional communication devices such as earphones in that they are smaller in size and do not require occlusion of the ears in order to transmit signals properly. Their small size means that they are lighter in weight thus imposing less stress on the head, neck, and shoulders. They also have the ability to be attached to the inside of protective headgear such as helmets. By leaving the ears unoccluded, users are able to maintain a higher level of situation awareness because the ears are left open to receive signals from the environment (McBride et al., 2005; Walker and Stanley, 2005). Furthermore, localization is not impaired with the use of bone conduction communication devices as with traditional headphones that cover the pinnae. It is predominantly for these reasons that some tactical organizations are considering wider distribution of bone conduction radio communication devices.

1.1. Impact of voice type on intelligibility

In the majority of tactical organizations such as the ones mentioned previously, the workforce has always largely consisted of men. As a result, when the communication mechanisms used in

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doi:10.1016/j.ergon.2008.03.006

these fields were developed and tested, the primary users were male. However, with changes occurring in society in regards to the distribution of men and women in the workforce, developers of technology need to be sure their designs are capable of enhancing the performance of both male and female users.

Previous research has determined that female voices tend to have a higher pitch and double the fundamental frequency (250 Hz) of male voices (124 Hz) (Nixon et al., 1998). It has also been found that in normal living conditions the intelligibility of male and female speech is similar (Ellis et al., 1996, 2002); however, in environments with elevated levels of noise, research indicates that the female voice is not as intelligible as the male voice (Nixon et al., 1998). One possible explanation for poorer speech intelligibility in high noise environments is that the ambient noise may be closer to the fundamental frequency of the female voice, thus masking portions of the signal received by the listener (Nixon et al., 1998). Considering the fact that the aforementioned studies were conducted using traditional air conduction means of communication, the primary purpose of the current study was to determine if issues in intelligibility similar to those that exist with air conduction communication devices exist with bone conduction communication devices as well, specifically when used in high noise environments.

1.2. Impact of location on intelligibility

In the past, the mastoid process has been the primary location on the head used by most clinical bone conduction researchers (Frank, 1982; Stenfelt and Håkansson, 1999). However, some researchers (e.g., Studebaker, 1962) believe that there are problems with placing the vibrators on the mastoid such as significant variations in skin and tissue thickness on the mastoid between individuals when compared to other positions on the head. These variations can have a significant impact on the transmission of bone conducted signals. There is also more of a tendency for shifts in the position of the vibrator when placed on the mastoid, which may cause problems with obtaining repeatable results. Another problem when using the mastoid is the middle ear condition is likely to affect hearing intensity thresholds more at this location than at others. Lastly, the vibrator may be exposed to the outer ear when placed on the mastoid so the listener may hear some noise by air conduction instead of strictly via bone conduction thus possibly affecting situation awareness. (*Note*: This particular problem is not really relevant to bone conducted speech communication but is more of an issue for audiometric screening where it is necessary to isolate bone conducted signals in order to determine possible causes of hearing impairment.) Due to these issues, some researchers have suggested that instead of using the mastoid, vibrators should be placed on the forehead or vertex of the head (von Békésy, 1932; Hood, 1957; Link and Zwislocki, 1951; Studebaker, 1962; Dirks and Malmquist, 1969; Goodhill et al., 1970).

Studebaker (1962) compared three locations—the mastoid, forehead, and vertex—in a study to see which was the most effective based upon three criteria. The three criteria were the lowest pure tone bone conduction thresholds, smallest between and within subject variability, and least dependence on the condition of the middle ear. His findings showed that the forehead and vertex had higher thresholds than the mastoid at all frequencies. The vertex had slightly lower thresholds at lower frequencies than the forehead but at the higher frequencies the forehead had lower thresholds than the vertex. The mastoid had the lowest between and within subject variability at higher frequencies but at the lower frequencies it had the highest between subject variability. The bone conduction measurements taken at the vertex and forehead appeared to be less affected by changes in the middle ear (e.g., otitis media) than the ones tested at the mastoid. Such changes can cause a decrease in the performance of the middle ear.

McBride et al. (2005) expanded the research on the effectiveness of bone vibrator placement and instead of comparing only the three locations Studebaker used they investigated eleven positions across the head. Added to the mastoid, vertex, and forehead were positions that were then under consideration for bone vibrator placement and positions commonly used for electroencephalograph (EEG) electrode placement. The results of this study indicated that the best location for the bone vibrator was the condyle (the bony projection in front of the ear) because out of the eleven signals to which the participants were exposed (125-, 250-, 500-, 1000-, 2000-, 4000-, and 8000-Hz pure tones, white noise bursts, and pre recorded speech sounds) the condyle had the lowest average threshold for eight of the signals. For the other three signals the condyle had either the second or third lowest mean threshold. The second best location to place the vibrator based upon this study was the mastoid. The vertex and the jawbone came in third and fourth, respectively, out of the 11 positions.

In order to investigate the performance of bone conduction devices using more realistic signals (i.e., vocal signals), Osafo-Yeboah et al. (2006) conducted a study to evaluate the impact of bone vibrator location on speech intelligibility. In their study, five locations were tested (condyle, mastoid, temple, forehead, and chin) using the Callsign Acquisition Test (CAT). The vocal signal used in their study was a single male voice. The highest intelligibility scores overall resulted when the bone vibrator was placed on the condyle. The mastoid had the second best scores. The worst scores resulted from the forehead location.

To expand on the Osafo-Yeboah et al. (2006) study described above, the current study had a secondary purpose which was to determine if the location on which the bone conduction vibrator is placed has an equal impact on the intelligibility of male and female voices.

2. Method

2.1. Participants

Six male and six female students recruited from the undergraduate and graduate student population at the Daytona Beach campus of Embry-Riddle Aeronautical University participated in the study. The age range was 18–25 years (mean age = 21 years). All participants were required to take and pass an audiometric screening where they had to have air conduction hearing thresholds of 20 dB or below for octave band frequencies from 250 to 8000 Hz and the difference between the left and right ear at each of the frequencies screened could be no greater than 10 dB to qualify for the study. Participants also had to have no history of otologic pathology. If all criteria were met, participants were required to read and sign an informed consent form and complete a demographic questionnaire.

2.2. Apparatus

Both the audiometric screening and the speech intelligibility tests took place inside a sound attenuated booth. The equipment for the audiometric screening included a Fonix FA-12 digital hearing evaluator audiometer, push button, and Telephonics TDH-39P earphones. The equipment for the experiment consisted of a B-72 bone vibrator to present the speech signals; an adjustable