Effects of the Auditory Conduction Mode on Achievable Situation Awareness

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Abstract

Soldiers on the battlefield are confronted with many challenges. It is important for them to be able to multitask efficiently and effectively, e.g. receive and execute commands through radio communications from the command control center while remaining conscious of the happenings in their environment, oftentimes amidst different background noises. There are two means by which radio communications can be established on the battlefield: air conduction and bone conduction. It was hypothesized that the impact of background noise on situation awareness for bone conduction (BC) would be significantly different from that of air conduction (AC) for all conditions evaluated. It was expected that the intensity of an alert signal would be perceived at a lower intensity when using a BC vs. an AC system, signifying higher situation awareness achievable through BC communication systems. This research examined the effects of the sound conduction modes and background interference on the situation awareness achievable using an auditory warning signal under varying levels of background interference. For each trial, subjects were asked to identify a word communicated to them via Modified Rhythms Test (MRT) through either air or bone conduction device under background interferences of varying types and intensities. Results indicated that there was no statistical significance observed between achievable situation awareness based on mode although there was observed significance between background noise type and background signal intensities. For increased statistical power, additional data should be collected in order to validate such claims.

Keyword: Bone Conduction, Air Conduction, Situation Awareness

1. Introduction

In many application environments, there may be the need to dynamically plug the ears to protect listeners from very loud sounds or leave them open to access ambient sounds. Soldiers on the battlefield, for example, may need to block their hearing sometimes, and leave their ears uncovered at other times to aid in situational awareness. It is important for them to be able to multitask efficiently and effectively, e.g. receive and execute commands through radio communications from the command control center while remaining conscious of the happenings in their environment, oftentimes amidst different background noises.

Consider the scenario where an infantry warfighter is on the battlefield within an urban environment. Such a soldier needs to navigate the battlefield, know the exact positions of his comrades and enemies, and where to go when given a mission to execute. This soldier may be exposed to a full range of battleground noise in a mounted or dismounted role. The background noise may be high steady (continuous) and/or high impulse. The high steady noises are typically generated by vehicles and/or aircraft while high impulse noise may originate from weapons and/or explosions. In this scenario, the soldier is communicating with his/her command and control center. Due to the means of radio communication currently available and changing background noise, the soldier may be unaware of a bomb ticking which can be an auditory precursor to an explosion. By the time communication is complete, the bomb
explodes due to a lack of awareness resulting in loss of life. If the soldier had been conscious of his auditory environment while still maintaining intelligible communicating, the chances of survival could have increased.

This research aims to investigate the impact of noise type and intensity on a listener’s situation awareness and how this impact may differ between air conduction and bone conduction communication means. It was hypothesized that the impact of background noise on situation awareness for bone conduction would be significantly different from that of air conduction. In order to evaluate the effects of noise on situation awareness, one must first understand how communication can be accomplished within context and characteristics of noise interference.

1.1 Air and bone conduction

Air conduction and bone conduction are two physical means of transmitting energy from an external device to the inner ear and the energy may be transmitted from a device that is connected to a radio. Air conduction commences with the transmission of sound waves through the ear canal to the middle ear. Sound waves cause the ossicles of the middle ear to vibrate which results in the motion of the inner ear cochlear fluid. At this point, there is some transmission of bone-conducted sound pressure applied to various components of the ear but majority of that sound is reflected because of the impedance difference between air and bone [1]. The traditional air conduction method of communication uses boom microphone and audio transmitters that occlude the ears [2].

With bone conduction, sounds can be transmitted either through vibrations from the skull of the talker to a contact microphone or from a vibrator to the skull of the participant. When a bone vibrator is used to transmit audio signals, it could be placed directly to the bone via surgical procedure, or attached to the skin covering a prominent bony region. The sounds produced by these vibrations are transmitted through jaw, cartilage, and soft tissue [3].

1.2 Situation awareness

Several definitions of situation awareness (SA) exist in the literature. Billings [4] defines SA as “an abstraction that exists within our minds, describing phenomena that we observe in humans performing work in a rich and usually dynamic environment.” Sarter and Woods [5] stated that “situation awareness is based on the integration of knowledge resulting from recurrent situation assessments.” Endsley [6] defined SA as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.” There are many models of SA but the Endsley’s [7] three-level-based information processing model is the most popular. It describes SA as a product comprising three hierarchical levels: Level 1 SA is the perception of cues; Level 2 SA is the integration of pieces of information and a determination of their relevance to the person’s goals; Level 3 SA is where an operator is able to forecast future situation events and dynamics. According to Endsley [8], a critical part of SA is understanding how much time is available until some event occurs or some action must be taken. The “within a volume of space and time” contained in the definition of SA pertains to the fact that operators are the part of the world (or situation) that are of interest to them based on not only space (how far away some element is), but also how soon that element will have an impact on the operator’s goals and tasks.

1.3 Measurement of situation awareness

The measurement of SA offers an important index for evaluating system design and training techniques and for better understanding of human cognition [8]. Different individuals may use the different processes to arrive at the same state of knowledge, or may arrive at different states based on the same processes due to differences in comprehension and projection of acquired information or different mental models, schema, etc... Measures that tap into situation assessment processes, therefore, may provide information of interest in understanding how people acquire information; however, they will only provide partial and indirect information regarding a person’s level of
situation awareness. There are over thirty different approaches designed specifically for the measurement of SA and these can be categorized into the following types of SA measure: freeze probe recall types, real-time probe techniques, self-rating techniques, observer rating techniques, performance measures, and process indices [9].

Freeze probe techniques involve the administration of SA related queries online during ‘freezes’ in a simulation of the task under analysis. Typically, a task is randomly frozen, all displays and screens are blanked and a set of SA queries regarding the current situation at the time of freeze is administered. The main advantage of this technique is that it removes issues associated with collecting SA data post trial. This technique is criticized for its level of intrusion on task performance. Real-time probe techniques involve the administration of SA related queries online, but with no freeze under analysis. This reduces the level of intrusiveness. Self-rating techniques are administered post-trial and involve participants providing a subjective rating of their perceived SA via a rating scale of some sort. They are easy to use and are non-intrusive. Observer rating techniques involve Subject Matter Experts observing participants during task performance and then providing an assessment or rating of each participant’s SA. Using performance measures to assess SA involves measuring relevant aspects of participant performance during the task under analysis. Process indices involve recording the process that participants use in order to develop SA during the task analysis. The Situation Awareness Global Assessment Technique (SAGAT) and Situation Present Assessment Method (SPAM) are discussed below since either method may be suitable for assessing SA [10].

Endsley developed the SAGAT in which operators perform a simulated real-time task [7]. SAGAT is the most popular freeze probe technique. At unpredictable times, the real-time scenario is interrupted and the simulator screen goes blank. Then, the operator is asked a series of questions about events in the scenario. Accuracy of responding to questions is the main variable in this test. The SPAM is based on the assumption that SA involves simply knowing where to find information in the environment to find a particular piece of information, as opposed to remembering what that piece of information is [11]. The SPAM is a real-time probe. Operators are presented with queries about the situation while the situation remains present and while they continue to perform the primary task. Closed-response and/or open-response queries could be used. Response time, in addition to accuracy, is recorded. Because SPAM is predicated on how quickly a participant can retrieve information, latency of responding to a question is the dependent measure. However, response times for incorrectly answered question are discarded from the analyses. SPAM’s use of response time allows researchers to assess SA when it succeeds, rather than only when it fails [12]. In SPAM two SA measures are collected, the total number of correct responses, and the average amount of time it takes to respond correctly to a probe question, known as SPAM latency.

1.4 Sound

Sound has both physical and psychological properties. In terms of physical properties, sound can be characterized by frequency, intensity, and duration. A sound’s frequency refers to the number of times in which the sound pressure wave oscillates from a high to a low and back to a high. A sound’s intensity indicates the amount of physical power required to produce such a sound at a particular point in time and is typically measured in decibels (dB). Finally, a sound’s duration is represented by the amount of time an environment is acoustically disrupted.

On the other hand, psychological properties of sound are directly related to the experience of hearing by a listener and have been observed to represent a nonlinear function based on frequency. Since psychological properties of sound are related to the subjective experience of sound within the hearing system, a sound’s characteristics are subject to the individual experience of said sound. Even though both attributes of sound can be independently observed and measured, both forms must be understood in parallel. For example, a sound can physically exists within an environment however it must be within the range of a listener’s hearing thresholds to be perceived. With that being said, a sound’s intensity (physical) and/or loudness (psychological) will dictate a listener’s perception of said sound. In regards to the current experiment, all sounds presented were at intensities capable of being perceived within the testing environment for all experimental conditions explored.
2. Method

For the purpose of this experiment, listeners were presented with a series of auditory signals and were tasked to distinguish between alert signals, intelligible radio communication, amidst background noise interference which indicated an achievable level of auditory situation awareness. Signals presented to listeners were (1) radio signals via MRT presented through a BC or AC system, (2) background noise presented at various levels of intensity via surround sound loudspeakers and (3) an alert signal presented via a loudspeaker located directly behind the listener. The level of achievable auditory situation awareness was expected to be better (lower perceived signal intensity of alert signal) through utilization of the BC rather than the AC system due to the fact that BC systems allow for the auditory pathways to remain unoccluded during signal transmission.

2.1 Participants

Twenty-eight participants (N = 28) consisting of nine females and nineteen males were recruited from the University community to participate in the current study. Participants were screened for normal hearing (≤ 20dB HL) of pure tone octave band frequencies from 250 Hz – 8k Hz through both air and bone conduction pathways. Qualified participants possessed a hearing sensitivity less than or equal to 20 dB HL for all signals evaluated with symmetry within 10 dB HL in the air conduction mode. The experimental protocol was approved by the Institutional Review Board at NC A&T State University. Written consent was obtained from each subject prior to participation.

2.2 Instrumentation and Audio Signals

All data collected throughout the study was obtained within a sound attenuated booth in an attempt to control for contamination of the acoustic environment. Participants were presented with a series of audio signals throughout the study corresponding to the trial and experimental condition. To determine hearing sensitivity during pre-screening, a clinical audiometer (FA-10 Digital Audiometer) presented pulsed pure-tone stimuli to the participant’s left and right AC auditory pathways separately via Telephonic TDH-39 earphones while a Radioear B-71 presented bone conducted signals to the participant’s mastoid location on the skull.

During the experimental portion of the study, participants were presented with both audio stimuli and noise interference in all conditions evaluated excluding baseline trials. Three separate signals were presented to participants consisting of speech intelligibility signals, a situational awareness alert signal, and background noise interference. Speech intelligibility signals were generated by Modified Rhymes Test (MRT) software. Such signals were then amplified and presented to the participant via appropriate conduction mode (air / bone conduction) by a Samson Stereo Headphone four-channel amplifier inserted in line to allow participants to achieve optimal intelligibility under background interference levels. Background interference was a white or pink 1k Hz noise file modified through Sound Forge and presented to participants at 40, 60, or 80 dB SPLs based on experimental trial. Finally, participants were presented with a 1k Hz pulsed pure tone to represent the alert tone to be identified. The intensity of the alert tone began at -10 dB HL and incremented by 5 dB HLs as necessary. All signal intensities excluding speech intelligibility signals were measured using a Brüel & Kjaer calibrated Sound Pressure Level meter and stored within the experimental computer.

2.3 Design of Experiment

A 2 x 2 x 3 factorial and repeated-measures design was utilized in the current study. Participants’ speech intelligibility and the minimal acoustical situation awareness were evaluated based on two levels of conduction mode (air- and bone-conduction), two levels of background inference noise type (white and pink), and three levels
of background noise intensity (40, 60, and 80 dB SPL). The dependent variables were speech intelligibility, generated by Modified Rhymes Test (MRT) software, and stimuli intensity read from the FA-10 Digital Audiometer.

2.4 Procedure

During experimental trials, participants were tasked with conducting a speech intelligibility evaluation administered through a computer and mouse interface. During each trial, participants were instructed to remain acoustically aware of an alert signal presented within the listening environment. Participants were instructed to indicate their awareness of the signal via response button.

Once briefed on the task to be accomplished, participants were seated within the testing environment, fitted with the appropriate headset device, and instructed on how to conduct the speech intelligibility evaluation. A speech intelligibility trial run was administered prior to the official data collection to familiarize participants with the task and stimuli. Regardless of predetermined randomization order of trials, participants were first evaluated on speech intelligibility without presentation of background interference once fitted with either the air or bone conduction headset. It should be noted that signals were presented to only one audio pathway (Right Ear / Right Condyle) for air and bone conduction modes, respectively.

During each experimental trial, the experimenter was tasked with identifying participants’ hearing sensitivity of an alert signal under varying background intensities and background types. Participants were presented first with the background interference appropriate for the trial, then instructed to begin the MRT, and finally presented the alert signal in incrementing fashion after a ten-speech signal delay. The inserted delay was to ensure the participant was engaged in primary speech intelligibility task prior to identifying the alert signal. Figure 1 is a visual representation of the experimental task flow. It should be noted that all participants were evaluated on speech intelligibility and acoustical situation awareness for all experimental conditions and conduction modes.

Presentation of all signals were randomized first by conduction mode, then background interference type, and finally by background noise intensity. Speech Intelligibility baselines were collected with the absence of background interference through both conduction modes and background interference types.

Figure 1: Experimental Task Flow
2.5 Data Analysis

An ANOVA was performed in SPSS software to test the significance of main effects and interactions. Prior to using ANOVA, residual analysis was used to check for model adequacy and assumptions. A p-value of 0.05 was used as the criterion for statistical significance in ANOVA.

3. Results

From the ANOVA results, there was no significant interaction between conduction mode, background type and background intensity ($F_{2, 23} = 0.124, p=0.884$), between conduction mode and background type ($F_{1, 24} = 0.360, p=0.554$), between conduction mode and background intensity ($F_{2, 23} = 0.250, p=0.781$), and between background type and background intensity ($F_{2, 23} = 2.048, p=0.152$). The main effects for conduction mode ($F_{1, 24} = 0.007, p=0.932$) is not significant. The main effects for background type ($F_{1, 24} = 23.514, p=0.0001$) and background intensity were significant ($F_{2, 23} = 1072.794, p=0.0001$).

The post hoc analysis showed significant difference in alert stimuli intensity between background types (white and pink) with a mean difference of 3.667 dB HL ($p<0.05$). An additional post hoc analysis showed significant difference in <dependent variable(s)> between background intensity at 40dB and 60dB (mean difference=16.8 dB HL, $p<0.05$), between background intensity at 40dB and 80dB (mean difference=37.15 dB HL, $p<0.05$), and between background intensity at 60dB and 80dB (mean difference=20.35 dB HL, $p<0.05$).

Figure 2: Mean stimuli intensity vs. background intensity for white vs. pink background noise in air conduction mode

Figure 3: Mean stimuli intensity vs. background intensity for white vs. pink background noise in bone conduction mode

The plots in Figures 2 and 3 show the mean stimuli intensities against different background intensities for white vs. pink background noise in the two conduction modes.
Also of interest was the stimuli intensity for the two conduction modes in the two background noise, which is shown in Figures 4 and 5.

4. Discussion

The objective of this study was to investigate how different background noise impacts situation awareness in air conduction and bone conduction modes under varying background signal intensities and types. An adaption of SPAM was used to determine participants' threshold acoustical situation awareness achievable. “SPAM acknowledges that situation awareness may sometimes involve simply knowing where in the environment to find the particular piece of information, rather than remembering what that piece of information is. For example a controller need not store in memory the call sign of an aircraft, but good SA may require that he or she knows where to find the call sign should communication with the aircraft be required” [11]. In this study the situation awareness was measured by the level at which the stimulus signal intensity could be perceived at three different intensities, two different background noises, and two conduction modes.

Although results from the current study showed that there were no statistically significant differences observed between conduction modes, there was a significant difference in the impact of white and pink background noise on the situation awareness in both conduction modes at varying levels of background intensity levels. This indicates that despite there being no difference in SA achievable by air and bone conduction, the background type and intensity has an effect on how well a listener can be acoustically aware of their environment.

When addressing concerns within the study, the first thing that was observed was the fact that only a signal location in both air and bone conduction were used for perception. In a traditional model, most air conduction devices require the use of both ears. With that being said, it would be interesting to see whether the same results will hold true when other locations (bone conduction) and both air conduction pathways are tested. In addition, once a non-significant p value was observed for conduction mode, an analysis of power was conducted to determine whether or not a large enough sample was acquired. It was determined that the power for conduction mode was 0.051, therefore it was concluded that increasing the sample size might cause a change in the results.
5. Conclusion

In conclusion, this study investigated how different background noise impacts acoustical situation awareness while communicating through air conduction and/or bone conduction devices using a Modified Rhythms Tests, under both white and pink background noise types at three different signal intensities. Overall, results showed that there is no significant difference in the achievable situation awareness between air conduction and bone conduction under varying background noise however further analysis can be done to determine the strength of such claims due to a low observed power. With accurate results, applied engineering psychologists will have a better understanding of the operational capabilities of the two communication devices.

References