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User Evaluation of a Bone Conduction Communication Headset During the Patriot 2007 Joint Field Training Exercise

by Phuong K. Tran, Mary S. Binseel, and Tomasz R. Letowski

ARL-TR-5973 **April 2012**

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14. ABSTRACT
Despite many advantages utilizing bone conduction (BC) technology, it has not yet made inroads in military communications applications. Military systems applications need to be subjectively evaluated by Soldiers to assess their utility and acceptance in military environments. In this study, a commercial BC headset was used and evaluated by the National Guard Special Operations Forces (SOF) during the 2007 Joint Field Training Exercise. Five participants wore BC headsets for 40 continuous hours during sustained operations. After completing the mission, the participants rated the BC communication system regarding speech intelligibility (SI), situation awareness, face-to-face communication, comfort, ease of use, and overall satisfaction of the device, and were asked to provide suggestions for improvement. The participants were also asked to rate an air conduction (AC) headset for comparison. The overall rating score for the BC headset was high (5/5) compared to the AC system (2.5/5), indicating the technology was favored over the AC system. The BC headset was chosen over the AC due to its light weight and because it allowed the user to maintain awareness of ambient sound. However, some important issues and suggestions for improvement were raised, including the need to ruggedize the system and to incorporate a quick-disconnect cable.

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bone conduction headset, user evaluation, speech intelligibility, comfort, case of use

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Contents

List of Figures

List of Tables

1. Introduction

In July 2007, researchers at the U.S. Army Research Laboratory's Human Research and Engineering Directorate (ARL/HRED) conducted an assessment of cognitive readiness of military personnel participating in the annual Patriot Field Training Exercise (FTX) at Volk Field and Fort McCoy, Wisconsin. This annual exercise provides military personnel the opportunity to develop and master unit specific training requirements while operating in a joint environment. The U.S. Army National Guard, the U.S. Air National Guard together with military units from Canada and the Netherlands participated in the exercise. The goal of the ARL/HRED study was to assess the degree to which cognitive readiness metrics can be used as a predictor of Soldier battlefield performance. This study offered an opportunity to conduct user acceptance evaluation of bone conduction (BC) communication devices as a part of general human-system integration evaluation process.

BC communication devices are a non-traditional means of radio communication. Under normal operational conditions, humans hear acoustic signals primarily through air conduction pathways involving the outer, middle, and inner ear structures. Air-conducted (AC) sounds arrive as pressure waves at the outer ear, travel through the ear canal, and induce movements of the tympanic membrane (eardrum) separating the ear canal from the middle ear. The movements of the tympanic membrane are transmitted through the chain of bones (ossicles) of the middle ear to the inner ear (cochlea) where they are converted into neural signals transmitted to the brain via the vestibulorcochlear nerve (Emmanuel and Letowski, 2009). Alternately, BC hearing is a result of skull and tissue vibrations caused by sound waves impinging on the skull or vibrations caused by a listener's own vocalizations (Henry and Letowski, 2007). These vibrations directly stimulate the middle and inner ear, bypassing the outer ear air conduction pathway. Normally, these BC pathway sounds are masked by the concurrent AC component of the sound, which are typically 40−60 dB stronger for the same sound stimulus. However, BC perception of acoustic signals can also be induced by direct vibration of tissue, especially bones, via BC vibrators in contact with the body, particularly on various head areas, which are associated with strong BC sound pathways. Such signals can be clearly heard even in the presence of AC sounds and their audibility is enhanced when the ears are occluded by hearing protection devices. BC microphones can also pick up a talker's voice signals from skull vibrations induced by the talker's own speech (Henry and Letowski, 2007); however, this study evaluated BC signal reception from BC vibrators only.

The use of BC for radio communications in military operations has many potential advantages. Because the external ear structures are not involved or covered by a communications system, a BC headset does not affect auditory situation awareness of the user, and hearing protectors, if

needed, can be independently selected to fit the mission rather than to accommodate communication needs of the user. Also, if the user wishes to conceal that they are using a BC headset, the vibrators can be placed in a cap or similar headgear with virtually no visible cues of their presence. Stealthy operation is also possible because of the ability to communicate using teeth clicks or other non- or sub-vocal signals, which are sensed by BC microphones. BC microphones are very resistant to surrounding noise and vibration so they can be successfully used in high-noise/high-vibration environments, such as in tracked vehicles, with sound quality approaching that of high quality noise-cancelling boom microphones (Henry and Mermagen, 2004; Tran et al., 2008; Tran and Letowski, 2010).

The use of BC in commercial applications is well accepted—for example, in the SwiMP3 audio player, the BC Aqua FM snorkeling system, and the Jawbone for cell phones. However, despite the promise held by BC communications, the technology has not been adopted in military systems. Although there is a wealth of information regarding the performance of BC headsets (Letowski et al., 2004; Scharine et al., 2005; Walker et al., 2005; Henry et al., 2009; Tran and Letowski, 2010; McBride et al., 2010), it has not been evaluated by the user community in an operational setting. This is mainly because the components (BC vibrators and microphones) needed for the unique requirements of communications in a military environment have not been readily available. It is only very recently that promising components have been developed (e.g., BC headsets of Oiido, Sweden and BC microphones of Sensory Devices Inc., USA). Thus, it is an appropriate time to integrate these components and evaluate their effectiveness in an operational environment.

The objective of this study was to conduct a Soldier-user evaluation of a BC communication system. The evaluation was based on 40 h of operational usage of the Oiido BC system and subjective comparison of this system against the Peltor AC system that has been used by the U.S. Special Forces. The participants completed a questionnaire on the perceived quality of radio reception, ease of use, ability to hear the surrounding environment, and comfort of both systems.

2. Methodology and Instrumentation

The Patriot FTX is a yearly joint exercise; the missions within the FTX were not designed by ARL/HRED. The FTX command allowed ARL/HRED to collect data on and from Soldier participants during the FTX while they performed their missions. The scenario chosen for evaluation of the communications headsets was a 40-h search-and-rescue mission at the Fort McCoy location (see figure 1). The Soldiers participating in the evaluation were asked to wear the Oiido BC headset for the continuous 40 h duration of the mission. All participants self-reported strong familiarity with the wear, comfort, and efficacy of the Peltor AC headset; however, these were unavailable during the FTX and, therefore, the participants used only the

BC headset. Questionnaire responses regarding the Peltor AC headset were based on their prior experiences with the system.

Figure 1. A section of the natural terrain area designated as the location for the SOF search and rescue mission and for the land navigation exercises at Fort McCoy, WI.

Prior to the mission, the Soldiers were instructed in the use of BC systems. The mission was not repeated and researchers were not able to interact with the Soldier participants after the mission started.

The BC headset consisted of two BC vibrators (SD2) and a noise-cancelling boom microphone manufactured by Oiido Corp (figure 2).

Figure 2. Oiido BC headset and combat arms earplugs.

The vibrators are positioned on the cheek bones in front of the user's ears (see McBride et al., 2005, 2006, 2008) and held in place with an adjustable headband, which hooks over the ears of the wearer and continues around the rear of the head. The headband also has a fabric strip over

the head to stabilize the headset and shift load bearing to the top of the head rather than ears. The boom microphone extends to the front of the user's mouth from the right bone vibrator. A coiled cable with a push-to-talk (PTT) switch connected the headset to the radio. In conjunction with the BC headset, the yellow non-linear (level dependent) side of the Combat Arms Earplugs (CAE) was worn to protect the wearers' hearing from harmful impulse noise, such as from gunshots. The radio used was a Thales Multiband Inter/Intra Team Radio **(**MBITR) AN/PRC 148 provided by the Special Operations Forces. The reference Peltor headset consists of circumaural (over-the-ear) earcups with loudspeakers mounted inside the earcups to transmit received radio signals to the wearer. The earcups also provide hearing protection. The microphone of the Peltor is a noise-cancelling boom microphone extending from the left earcup. The MBITR radio and the reference Peltor AC system are shown in figure 3.

Figure 3. MBITR radio and Peltor communication headset.

The evaluation instrument was a questionnaire designed to elicit participants' opinions about the comfort and efficacy of the two headsets in the operational environment. The questionnaire is included in appendix A.

2.1 Participants

Six Special Operations Forces (SOF) Soldiers (comprising one team) volunteered to participate in the study. A hearing screening was conducted with a portable audiometer (Maico MA41 and TDH39 headphone). Four participants had normal hearing (defined as pure tone hearing thresholds <25 dB HL at frequencies 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz); one participant had a mild hearing loss with hearing thresholds reaching 30–35 dB at some tested frequencies; and one participant had hearing loss at high frequencies in both ears, with hearing thresholds from 50–65 dB HL in the left ear and 40–55 dB HL in the right ear, at 3000 Hz and above. Participants' hearing was documented but there was no hearing requirement for participation. One Soldier with normal hearing was unable to complete the study for medical

reasons not related to any technical aspects of the study, so the data were gathered for five participants.

2.2 Procedure and Training

Prior to study participation, ARL/HRED researchers explained the purpose of the study and ensured that all participants understood their right to withdraw from the study at any time and that no command pressure was used to influence any of the participants' consent. The Soldiers who volunteered for the study were then asked to read and sign the Volunteer Agreement Affidavit. After signing the Volunteer Agreement Affidavit, the researchers conducted hearing screenings, explained how BC communications work, and instructed the Soldiers on the proper wear of the BC headset, especially with regards to component placement and head contact. Participants were also instructed in the functioning and proper wear of the CAE and were instructed to wear the non-linear (yellow) side of the CAEs when they wore the BC headset. The instruction on how to use the BC headset with the MBITR and how to properly insert and use the CAEs took about 10 min. The SOF Soldiers were instructed to pay particular attention to issues that would be evaluated after the exercise, such as comfort, ease of use, and speech intelligibility (SI) of the BC headset. After training, the participants kept the BC headsets to familiarize themselves with the system before performing the rescue scenario.

The out-brief questionnaire was handed to the participants at the end of their rescue exercise. The participants were asked to rate each of the two evaluated systems (Peltor AC and Oiido BC) on SI, situation awareness, face-to-face communication, comfort, ease of use, and overall effectiveness in conducting various types of activities. They were also asked to state their overall preference for a communication system and list the factors that influenced their choice. The rating scale for each questionnaire item was 1 to 5 where numbers "1" and "5" indicated the most negative (very bad) and positive (very good) ends of the scale, respectively.

2.3 Scenario

The BC headsets were used intermittently during the first two days of the FTX and continuously during the sustained operations (SUSOPS) training, which consisted of the search-and-rescue scenario. The SUSOPS exercise was conducted from Tuesday night to approximately Thursday noon, lasting about 40 h. The mission of the SOF team was to conduct a hostage rescue mission at a designated location. The main, ground-based, portion of the mission took place at Fort McCoy. Helicopters picked up the Soldiers at Volk Field and inserted them in a field at Fort McCoy. The mission required proceeding about four miles through woods and swamps, with surprise attacks from opposition forces, prior to reaching the hostage location. The terrain was hilly and rough. Participants' headborne equipment included the BC headsets, CAEs, night vision goggles, and a soft cap.

3. Results

One participant did not complete the mission due to a medical emergency and, therefore, did not complete the questionnaire. Of the remaining five participants, one could not use the system throughout the entire mission due to breakage of the cable connecting the headset to the radio and only partially answered the out-brief questionnaire. The average rating score for five out of six participants on each question are summarized in table 1 and graphed in figure 4. The individual responses are listed in appendix B.

Table 1. Summary of rating scores.

Question	Average Rating and Standard Deviation (1 is very bad; 5 is very good)	
	Peltor AC Headset	**Oiido BC Headset**
How would you rate your ability to understand radio speech transmissions using the headsets?	4.6 ± 0.89	4.6 ± 0.89
How would you rate your ability to hear and understand sounds in your surroundings including face-to-face speech?	3.0 ± 1.41	5.0 ± 0.0
On a scale of 1 to 5, how would you rate the comfort of the headsets?	2.4 ± 0.89	4.8 ± 0.45
On a scale of 1 to 5, how would you rate the ease of use of the headsets?	3.2 ± 0.45	4.4 ± 0.89
On a scale of 1 to 5, how would you rate the headsets overall, based on many mission types?	*2.5 ± 1.00	*5 ± 0.00
Which headset do you prefer? (1 is strongly prefer the Peltor headset, 5 is strongly prefer the BC headset) What was important factor of your choice?	*4.75 ± 0.50	
	Factors: Light weight and awareness of ambient noise	

* Average rating score for four out of six participants.

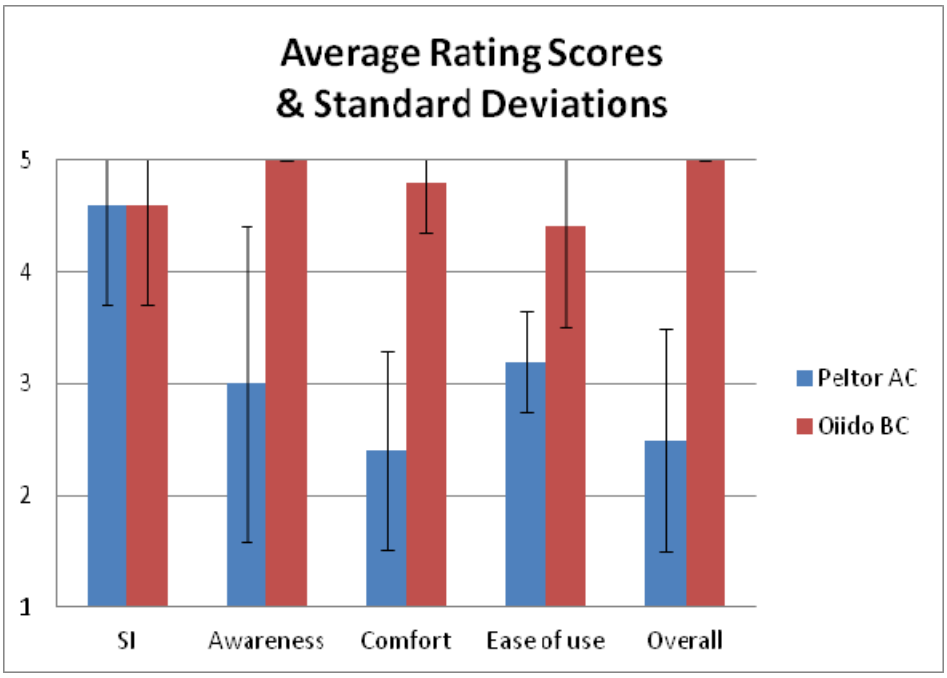

Figure 4. Graph of average rating scores.

Both the Oiido BC and Peltor AC systems had the same high score in SI at 4.6. However, on situation awareness, face-to-face communication, comfort, and ease of use, the BC headset was judged superior to the Peltor headset, with average scores for the Oiido BC headset ranging from 4.4 to 5 compared to those from 2.4 to 3.2 for the Peltor AC headset. For the question "How would you rate the headsets overall, based on many mission types?" all the participants gave the BC headset a maximum rating score of 5, while giving the Peltor system only 2.5. All participants preferred the BC headset over the Peltor AC system. Its light weight and the awareness of ambient sound were the main reasons given for their preference. No statistical analysis was performed due to the small number of data points.

4. Discussion

In general, the Oiido BC headset was rated quite favorably by the SOF participants compared to the Peltor AC headset. The Oiido BC system was judged quite comfortable to wear, more so than the Peltor AC system. Speech produced by the systems was evaluated as equally intelligible. In addition, while the participant who had signs of hearing loss complained that the Peltor AC system was not loud enough, he did not complain about the Oiido BC headset and rated this system very high on SI. One participant made a remark that he wore the BC headset 40 h straight and felt fine, while he could not do it with headsets that occlude the ears. However, another participant complained about the Oiido BC system creating uncomfortable pressure at

four points on his head, possibly indicating maladjustment, or need for greater headband adjustability, with the Oiido BC system. In addition to the Oiido BC headset itself, the participants also commented on the properties of the communication system as a whole. They preferred a straight cable to a coiled cable and wanted a bigger PTT button. Other comments and suggestions regarding the Oiido BC headset were:

1. The headset needs to be more durable, made with stronger materials, ruggedized for military use.
2. The headset needs a pullout (quick disconnect) connector to detach the headset at the PTT button.
3. The boom microphone should be more like the size of the Bluetooth-type ear-mounted headsets used with cell phones, not extending so far around the face.
4. The bone vibrators should detach and clip to sunglass frames

The system also worked quite well in a high noise environment. During the exercise, the researchers had an opportunity to demonstrate the BC system to a Royal Netherlands Air Force medical team at Volk airport.

After the demonstration, two flight nurses volunteered to wear the Oiido headsets (see figure 5) with foam earplugs during their mission. The scenario was a medical evacuation of an injured Soldier in a Chinook helicopter (see figure 6).

Figure 5. Two nurses wearing Oiido BC headsets before the exercise.

Figure 6. A team of medical personnel evacuated an injured Soldier with a Chinook helicopter during exercise.

The team was flown to the location of the "injured" Soldier, recovered the Soldier, and was flown back to their origin location. These nurses communicated to each other via radios during their flight. When they returned, they both gave a thumbs-up with big smiles. They commented "very good, I don't have to yell at all". One of the researchers asked "If you have to give the headset from 1 to 5 points, 5 is very good and 1 is very bad, what number would you give?" Both nurses agreed that they would give the headset 5 points.

5. Conclusions

This study was a field study of the users' acceptance of BC communication systems. The number of participants was too small for inferential statistical analysis; however, the preference for the BC headset among participants was strong enough to warrant reporting and further evaluation of BC systems in military environments. The questionnaire data reveal unanimous preference for the Oiido BC communication system over the Peltor AC system. However, it must be emphasized that this comparison was based on participants' previous experience with the Peltor AC system, not on a head-to-head direct comparison basis. The anecdotal data from the flight nurses were also positive in terms of the utility of the BC headset. Further studies will need to include greater numbers of Soldiers in operational environments and larger number of types of BC headsets to develop minimum technical requirements for BC systems for military applications.

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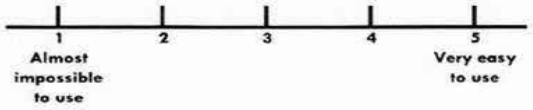
Appendix A. Questionnaire

This appendix appears in its original form, without editorial change.

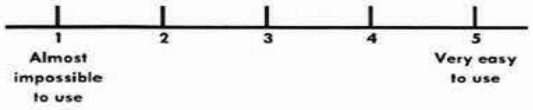
G1. On a scale of 1 to 5, how would you rate your *ability to understand speech* using the headsets? (circle a number)

Current (Peltor)



What were specific problems you had with your ability to understand speech when wearing the current (Peltor) headset, if any?

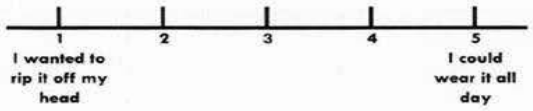
Bone Conduction (Headset only - not earplugs)



What were specific problems you had with your ability to understand speech when wearing the bone conduction headset, if any?

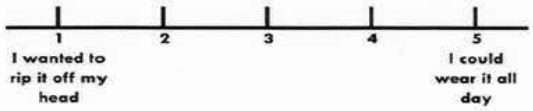
G2. On a scale of 1 to 5, how would you rate the *comfort* of the headsets? (circle a number)

Current (Peltor)



What were specific problems you had with the comfort of the current (Peltor) headset, if any (such as heat, pressure, rubbing)?

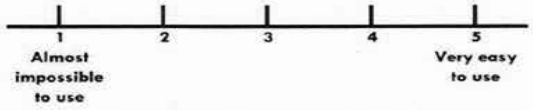
Bone Conduction (Headset only - not earplugs)



What were specific problems you had with the comfort of the bone conduction headset, if any (such as heat, pressure, rubbing)?

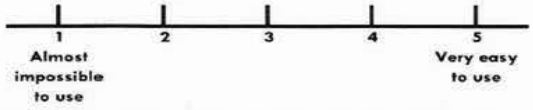
G3. On a scale of 1 to 5, how would you rate the *ease of use* of the headsets? (circle a number)

Current (Peltor)



What were specific problems you had with the ease of use of the current (Peltor) headset, if any?

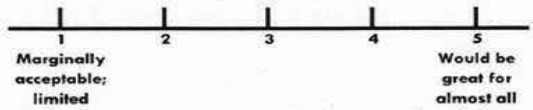
Bone Conduction (Headset only - not earplugs)



What were specific problems you had with the ease of use of the bone conduction headset, if any?

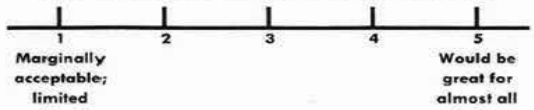
G4. On a scale of 1 to 5, how would you rate the headsets *overall*, based on many mission types? (circle a number)

Current (Peltor)



Why did you rate the current (Peltor) headset as you did?

Bone Conduction (Headset only - not earplugs)



Why did you rate the bone conduction headset as you did?

Do you have any other comments or additional insights?

Appendix B. Individual Response Summary

This appendix appears in its original form, without editorial change.

On a scale 1 to 5, how would you rate your ability to understand radio speech transmissions using the headsets?

	Peltor AC headset		Oiido BC headset	
Subject	score	comments	score	comments
1	3	not loud enough	5	not worse, not good, need hearing protector
2	5		3	
3	5		5	
4	5		5	
5	5		5	
Average	4.6		4.6	
Stddev	0.89		0.89	

On a scale of 1 to 5, how would you rate your ability to hear and understand sounds in your surroundings including face-to-face speech?

	Peltor AC headset		Oiido BC headset	
Subject	score	comments	score	comments
1	3		5	
2	3		5	
3	5		5	
4	3		5	
5	1		5	
Average	3		5	
Stddev	1.41		0	

On a scale of 1 to 5, how would you rate the comfort of the headsets?

	Peltor AC headset		Oiido BC headset	
Subject	score	comments	score	comments
1	3	K-pot too confining	4	I wore it almost 2 days, started to feel like Frankenstein
2	1		5	
3	3		5	I feel 4 point pressure on my head
4	2		5	I wore it 40 hours feel fine
5	3		5	
Average	2.4		4.8	
Stddev	0.89		0.45	

On a scale of 1 to 5, how would you rate the ease of use of the headsets?

	Peltor AC headset		**Oiido BC headset**	
Subject	score	comments	score	comments
1	3		4	cable needs compatibility with other sets
2	3		3	
3	4		5	
4	3		5	
5	3		5	
Average	3.2		4.4	
Stddev	0.45		0.89	

On a scale of 1 to 5, how would you rate the headsets overall, based on many mission types?

	Peltor AC headset		**Oiido BC headset**	
Subject	score	comments	score	comments
1	3		5	
2				
3	3		5	
4	3		5	
5	1		5	
Average	2.5		5	
Stddev	1		0	

Which headset do you prefer? (1 is strongly prefer the Peltor headset, 5 is strongly prefer the BC headset) And what was the important factor of your choice?

Subject	Score	Comments
1	4	Make it better
2		N/A
3	5	I strongly prefer the BC headset
4	5	I strongly prefer the BC headset
5	5	I strongly prefer the BC headset. Important factor: light weight & aware of ambient noise
Average	4.75	
Stddev	0.5	

Do you have any other comments, suggestions or insights about the headsets?

Subject	Comments
1	**None**
2	Not made for rugged use, must be made of stronger materials. I broke headset during mission infill.
3	None
4	Need more durable, PTT bigger, connector pullout at PTT in order to detach them, microphone could be like Bluetooth size, not in face, BC pieces need to detach and clip to sunglass frames.
5	None

List of Symbols, Abbreviations, and Acronyms

AC	air-conducted
ARL	U.S. Army Research Laboratory
BC	bone conduction
CAE	Combat Arms Earplugs
FTX	field training exercise
HRED	Human Research and Engineering Directorate
MBITR	Multiband Inter/Intra Team Radio
PTT	push-to-talk
SI	speech intelligibility
SOF	Special Operations Forces
SUSOPS	sustained operations

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