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AUDIO DISPLAY HARDWARE INVESTIGATION FOR FUTURE DISMOUNTED SOLDIER COMPUTER SYSTEMS

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Abstract

Audio displays are required to provide radio communications, multi-channel auditory information, and 3D audio feedback that can be perceived by soldiers in a high-noise, combat environment without decreasing the soldier's ability to detect local sounds and voices in the free field. A comparison of five types of audio displays (bone conduction, in-ear, unoccluded headset, partial and fully occluded headset) was conducted based upon existing literature, user feedback and the authors' experience. This report presents the results of that comparison. Overall, the bone conduction headset is rated better than the other types of audio displays because it has unique advantages in terms of Free Field Sound Detection, Equipment Compatibility, Fit and Comfort, Tactical Feasibility, and Durability. The bone conduction headset is best suited for the tasks of soldiers where durability, comfort, and compatibility with helmets and other equipment are critically important. The bone conduction headset provides the unique advantage of enabling the wearer to simultaneously hear system-generated and free field sounds. The fully occluded circumaural headset was rated second best overall and has unique advantages in terms of Spatialization. The occluded headset is the best system for displaying 3D audio information. The fully occluded and in-ear headsets are rated highest in terms of Audio Display Performance and Sound Discrimination. Each of these systems is capable of providing strong attenuation of external free field sounds in a high-noise environment.

Résumé

Des dispositifs de reproduction audio sont nécessaires pour fournir aux fantassins de l'information audio et des rétroactions sonores tridimensionnelles par multiples canaux de radiocommunications, d'une façon qui permette la perception dans un environnement de combat à bruit intense sans pour autant réduire l'aptitude des fantassins à détecter localement les sons et les voix en champ libre. Dans l'ensemble, le dispositif à conduction osseuse a devancé les autres types de dispositifs de reproduction audio en raison de ses avantages uniques quant à la détection sonore en champ libre, à la compatibilité de l'équipement, à l'adaptation et au confort, à la faisabilité tactique et à la durabilité. Le dispositif à conduction osseuse convient particulièrement aux tâches de fantassin pour lesquelles la durabilité, le confort et la compatibilité avec des casques ou d'autres équipements revêtent une extrême importance. Le dispositif à conduction osseuse offre un avantage unique : il permet d'entendre simultanément les sons provenant du système et ceux qui sont produits en champ libre. Le dispositif circumaural à occlusion complète s'est classé au deuxième rang et offre des avantages uniques du point de vue de la spatialisation. Le dispositif à occlusion constitue le meilleur moyen de reproduire l'information audio tridimensionnelle. Le dispositif à occlusion complète et l'oreillette se sont classés au meilleur niveau pour ce qui est du rendement de reproduction audio et de la discrimination sonore. Chacun de ces dispositifs est capable d'atténuer fortement les sons externes en champ libre, dans un environnement à bruit intense.

Executive Summary

Audio display systems are required to provide the soldier with radio communications, multi-channel auditory information and feedback that can be perceived in a high-noise, combat environment without reducing or limiting the soldier's ability to detect local sounds and voices in the free-field. In the event free-field hearing is obstructed, (e.g. full encapsulation), the audio display system is required to provide a means of receiving and displaying free-field sounds and voice communications. A comparison of five types of audio displays was conducted based upon existing literature, user feedback and the authors' experience. This report presents the results of that comparison. Options investigated included fully occluded acoustic, partially occluded acoustic, open ear acoustic, in-ear acoustic, and bone conduction. These devices were classified according to the following criteria: enclosure type, fit, noise attenuation or reduction, and talk-through.

The devices were evaluated and compared according to ten performance criteria: Free Field Sound Detection, Audio Display Performance, Sound Discrimination, Equipment Compatibility, Fit and Comfort, Tactical Feasibility, Spatialization, Reliability, Durability, and Availability and Cost. A list of advantages and disadvantages was created for each type of device based on review of the available product information, experience evaluating the devices during previous field trials, and expert human factors evaluation based on prior domain knowledge and user feedback. Weights were systematically assigned to each of the performance rating criteria.

Each system has special features that could provide advantages to soldiers. The fully occluded acoustic headset provides an isolated listening environment and ballistic protection from noise in the free field. The partially occluded acoustic headset provides an optimal listening environment while also enabling the wearer to detect sounds in the free field. The open ear acoustic headset is a very reliable system that provides a constant audio source without interfering with detection of sounds in the free field. The in-ear acoustic headset provides an isolated listening environment and is compatible with all types of helmets. The bone conduction headset does not cover the ear and does not interfere with detection of sounds in the free field.

Several disadvantages were identified for each of the devices. The fully occluded acoustic headset interferes with the detection of sounds in the free field. The circumaural enclosure prevents passive detection of external sounds because it prevents free field sounds from reaching the ear. The partially occluded headset allows loud free field noises to pass through the enclosure and interfere with the wearer's perception of the audio signal. The open ear acoustic headset can increase the risk of enemy detection because the open enclosure allows sound to escape. The in-ear acoustic headset can interfere with detection of free-field sounds and can potentially cause discomfort with prolonged use. The bone conduction headset will not transmit an audio signal to the wearer if the bone conduction transducer looses contact with the wearer's head.

Performance ratings were tallied and devices were ranked according to their total score. Overall, the bone conduction headset is rated better than the other types of audio displays. The bone conduction headset has unique advantages in terms of Free Field Sound Detection, Equipment Compatibility, Fit and Comfort, Tactical Feasibility, and Durability. The bone conduction headset is best suited for the tasks of soldiers where comfort for prolonged use, compatibility

with helmets and other equipment and durability are critically important. The bone conduction headset provides the unique advantage of enabling the wearer to simultaneously hear system-generated and free field sounds.

The fully occluded circumaural headset was rated second best overall and has unique advantages in terms of Spatialization. The occluded headset is the best system for displaying 3D audio information. The fully occluded and in-ear headsets are rated highest in terms of Audio Display Performance and Sound Discrimination. Each of these systems is capable of providing strong attenuation of external free field sounds.

The fully occluded circumaural and partially occluded headsets are rated highest in terms of Reliability. Both of these systems are designed to stay aligned to the ear and can function if direct contact is lost. The partially occluded circumaural and open ear supraural acoustic headset are reated best in terms of Availability and Cost because these systems are commercially available and are inexpensive to manufacture.

Sommaire

Les dispositifs de reproduction audio sont nécessaires pour fournir aux fantassins de l'information et des rétroactions sonores par multiples canaux de radiocommunications, d'une façon qui permette la perception dans un environnement de combat à bruit intense sans pour autant réduire ni limiter l'aptitude des fantassins à détecter localement les sons et les voix en champ libre. En cas d'obstruction du champ acoustique libre (p. ex. d'encapsulation complète), les dispositifs de reproduction audio doivent permettre de recevoir et de reproduire les sons et communications vocales en champ libre. Une comparaison de cinq types de dispositifs de reproduction audio a été faite d'après la documentation existante, la rétroaction des utilisateurs et l'expérience des auteurs. Le présent rapport en donne les résultats. Voici les dispositifs qui ont été étudiés : casque acoustique à occlusion complète, casque acoustique à occlusion partielle, casque acoustique sans occlusion, casque acoustique intra-auriculaire et casque à conduction osseuse. Les dispositifs ont été classés selon les critères suivants : type de montage, adaptation, atténuation ou réduction du bruit et intercommunication.

Les dispositifs ont été évalués et comparés selon dix critères de rendement : détection sonore en champ libre, rendement de reproduction audio, discrimination sonore, compatibilité de l'équipement, adaptation et confort, faisabilité tactique, spatialisation, fiabilité, durabilité, et disponibilité et coûts. Une liste d'avantages et d'inconvénients a été créée pour chaque type de dispositifs, selon l'examen de l'information disponible sur les produits, l'expérience tirée de l'évaluation de dispositifs durant des essais antérieurs sur le terrain et l'évaluation de facteurs humains par des experts à partir de la connaissance antérieure du domaine et des réactions des utilisateurs. Une pondération a été affectée systématiquement à chacun des critères d'évaluation du rendement.

Chaque dispositif offre des caractéristiques spéciales qui pourraient se révéler avantageuses pour les fantassins. Le dispositif acoustique à occlusion complète crée un environnement d'écoute isolé et assure une protection balistique contre le bruit en champ libre. Le casque acoustique à occlusion partielle crée un environnement d'écoute optimal tout en permettant à l'utilisateur de détecter les sons en champ libre. Le casque acoustique sans occlusion est très fiable et constitue une source audio constante qui ne gêne pas la détection des sons en champ libre. Le casque acoustique intra-auriculaire crée un environnement d'écoute isolé et est compatible avec tous les types de casques protecteurs. Le casque à conduction osseuse ne recouvre pas l'oreille et ne gêne pas la détection des sons en champ libre.

Plusieurs inconvénients ont été mis en évidence pour chacun de ces dispositifs. Le casque acoustique à occlusion complète gêne la détection des sons en champ libre. Le montage circumaural empêche la détection passive des sons externes du fait qu'il ne permet pas aux sons en champ libre d'atteindre l'oreille. Le casque acoustique à occlusion partielle utilise un type de montage qui n'empêche pas le bruit intense en champ libre d'atteindre l'oreille, ce qui nuit à la perception du signal audio. Le casque acoustique sans occlusion peut accroître les risques de détection par l'ennemi, car le montage de type ouvert laisse les sons s'échapper. Le casque acoustique intra-auriculaire peut gêner la détection des sons en champ libre et risque de créer de l'inconfort après une utilisation prolongée. Le casque à conduction osseuse ne transmet pas de

signal audio à l'utilisateur lorsque le transducteur à conduction osseuse perd contact avec la tête de la personne.

Des évaluations de rendement ont été établies, et les dispositifs ont été classés en fonction de leur note totale. Dans l'ensemble, le casque à conduction osseuse s'est classé avant les autres types de dispositifs de reproduction audio. Le casque à conduction osseuse offre des avantages uniques du point de vue de la détection sonore en champ libre, de la compatibilité de l'équipement, de l'adaptation et du confort, de la faisabilité tactique et de la durabilité. Le casque à conduction osseuse convient particulièrement aux tâches de fantassin pour lesquelles le confort durant une utilisation prolongée, la compatibilité avec des casques protecteurs ou d'autres équipements et la durabilité revêtent une extrême importance. Le casque à conduction osseuse offre un avantage unique : il permet d'entendre simultanément les sons provenant du système et ceux qui sont produits en champ libre.

Le casque circumaural à occlusion complète s'est classé au deuxième rang et offre des avantages uniques du point de vue de la spatialisation. Le casque à occlusion constitue le meilleur moyen de reproduire l'information audio tridimensionnelle. Le casque à occlusion complète et le casque intra-auriculaire se sont classés au meilleur niveau pour ce qui est du rendement de reproduction audio et de la discrimination sonore. Chacun de ces dispositifs est capable d'atténuer fortement les sons externes en champ libre.

Le casque circumaural à occlusion complète et le casque à occlusion partielle ont devancé les autres du point de vue de la fiabilité. Ces deux dispositifs sont conçus pour rester alignés avec l'oreille et peuvent continuer de fonctionner après la perte du contact direct. Le casque circumaural à occlusion partielle et le casque acoustique supra-aural sans occlusion se situent au premier rang pour ce qui est de la disponibilité et des coûts étant donné qu'ils sont disponibles sur le marché et que leur fabrication est peu coûteuse.

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1. Introduction

Audio displays are required to provide the soldier with radio communications, multi-channel auditory information and feedback that can be perceived in a high-noise, combat environment without reducing or limiting the soldier's ability to detect local sounds and voices in the free-field. In the event free-field hearing is obstructed, (e.g. full encapsulation), the audio display system is required to provide a means of receiving and displaying free-field sounds and voice communications. Options investigated include fully occluded acoustic, partially occluded acoustic, open ear acoustic, in ear acoustic, and bone conduction. These devices can be classified according to the following criteria: enclosure type, fit, noise attenuation or reduction, and talk-through.

Table 1. Audio Display Hardware Taxonomy

Display Attributes	**Fully Occluded Acoustic Headset**	**Partially Occluded Acoustic Headset**	**Open Ear Acoustic Headset**	**In Ear Acoustic Headset**	**Bone Conduction Headset**
Enclosure Type	Closed	Vented	Open (or helmet mounted)	Intra-aural	Open (or helmet mounted)
Fit	Circumaural	Circumaural	Supraural	Universal Foam or Plastic (or custom fit)	Must remain in contact with scull
Noise Attenuation or Reduction	Passive (or w/Active)	No (or w/Active)	No (or w/Active)	Passive (or w/Active)	No (or w/Active or w/Passive)
Talk-through (for free-field communication)	No (or w/Active)	Passive (or w/Active)	Open (or w/Passive)	Passive (or w/Active)	Open (or w/Active or w/Passive)
Features	Can Provide Ballistic Noise Protection			Wireless or Wired Can be used to transit speech	Can be used to transit speech

2. Method

Prior to conducting this investigation, the authors acquired extensive domain knowledge participating in several field trials to evaluate various audio headset configurations as part of the SIREQ TD program. These field trials evaluated the Marconi PRR headset and various alternative headset configurations (Woods, Tack, and Adams, 2003) for radio communication and for electronic speech recognition (Bos and Tack, 2004).

In order to evaluate and compare these systems, a set of performance rating criteria were defined considering relevant measures of human performance and the context of use (see Table 2). A list of advantages and disadvantages was created for each type of device based on review of the available product information, experience evaluating the devices during previous field trials, and expert human factors evaluation based on prior domain knowledge and user feedback.

Table 2. Definitions of Rating Criteria for Audio Displays

Rating Criteria	Definition of Rating Criteria
Free Field Sound Detection	A measure of the wearer's ability to detect sounds and to hear voices in the free field while wearing the audio display device.
Audio Display Performance	Loudness, clarity, and speech intelligibility of sound transmitted by the audio display device in ideal conditions.
Sound Discrimination	Ability of the wearer to perceive and comprehend sounds transmitted through the audio display device over background noise in the free field.
Equipment Compatibility	Compatibility of the audio display device with other types of equipment or clothing.
Fit & Comfort	Security of fit on the wearer and degree of comfort when wearing the audio display device.
Tactical Feasibility	Ability to move tactically without detection while wearing and listening to the audio display device.
Spatialization	Ability of the wearer to accurately perceive spatialized 3D audio transmitted by the audio display device. As a human-computer interface (HCI), 3D audio can be used to indicate spatial locations, including those outside the visual field.
Reliability	An estimate of the wearer's ability to repeatedly receive audio transmissions with the device without errors.
Durability	A measure of the strength of construction of the audio display device and the device's ability to endure field use without breaking.
Availability and Cost	The relative price and commercial availability of the audio display.

3. Results

3.1 Fully Occluded Acoustic Headset

Fully occluded headsets use a full enclosure and provide a circumaural fit around the wearer's ears. The enclosure provides passive noise attenuation to block ambient noise and reduces noise escaping from the headphone. Fully occluded headsets can be used in conjunction with active noise reduction and active talk through. These headsets also can be used to provide ballistic noise protection.

Figure 1. Thales RA108 Slimgard II

3.1.1 Advantages

a) Audio Display Performance: Fully enclosed headsets provide excellent sound quality. Professional audio recording engineers use fully occluded headsets for monitoring studio recordings.

b) Sound Discrimination: The enclosure isolates the soundstage from external noise which improves the perceived auditory signal to noise ratio. The fully occluded headset can also provide ballistic hearing protection.

c) Fit/Comfort: Circumaural headsets can fit securely against the head to provide a snug fit and reduce vibration during activity.

d) Tactical Feasibility: The enclosure isolates sounds generated by the audio display to prevent detection.

e) Spatialization: Occluded audio displays provide optimal channel separation and signal quality to each ear. Occluded headsets are recommended for presentation of 3D audio.

f) Reliability: The occluded headsets are mechanically simple and reliable. The wearer can hear audio displayed by the headset even if it shifts position or looses direct contact with the ear.

g) Durability: Occluded headsets use a hard shell and are constructed of reinforced materials to provide maximum strength and long service life.

h) Availability and Cost: Fully occluded headsets are commercially available. These headsets tend to include expensive speaker components and materials.

3.1.2 Disadvantages

a) Free Field Sound Detection: The circumaural enclosure prevents passive detection of external sounds because it prevents free field sounds from reaching the ear. Fully occluded headsets also interfere with verbal communications. While active or passive talk-through systems or manually operated vents can be used to provide access to external sounds, these cannot replicate the accuracy of the unaided human ear.

b) Equipment Compatibility: Due to their size and shape they tend to interfere with many types of helmets and other types of equipment worn on the head.

c) Fit/Comfort: Fully occluded headsets tend to be the largest and heaviest type of headset. Circumaural headsets tend to cause fatigue and discomfort with prolonged use because they can retain heat and press on the pinnae of the ear.

3.2 Partially Occluded Acoustic Headset

Partially occluded headsets use a vented enclosure and provide a circumaural fit around the wearer's ears. The earmuff completely covers the ear and greatly reduces the sound let out of the headphone and the ambient noise let into the headphone. They provide no passive noise attenuation but can be used in conjunction with active noise reduction. Partially occluded headsets can provide passive or active talk through.

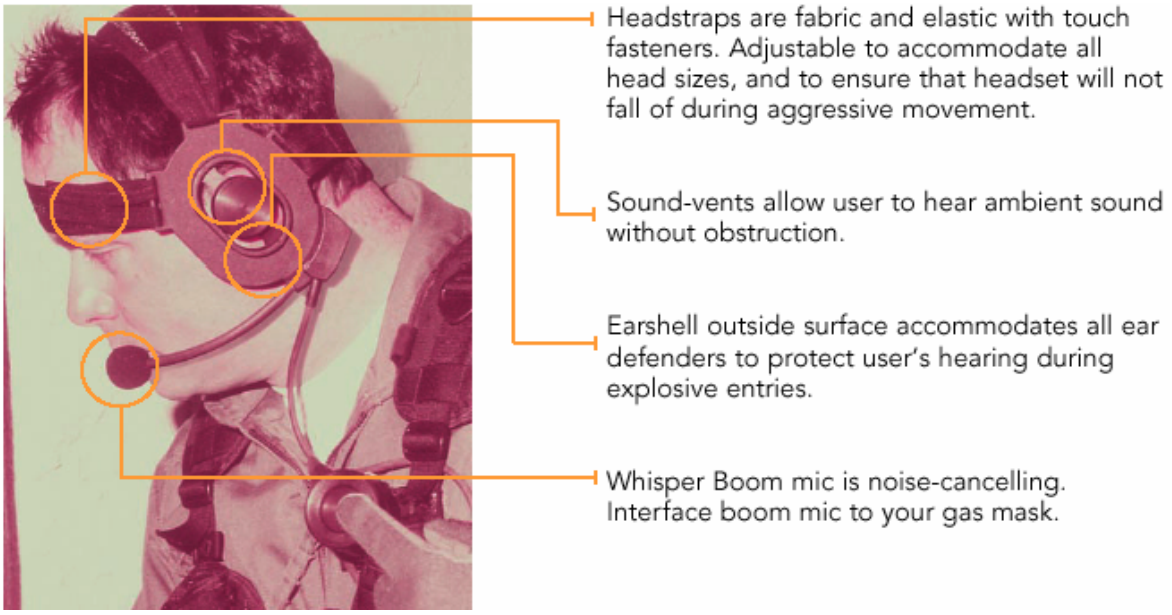

Figure 2. Lite2 Partially Occluded Headset

3.2.1 Advantages

a) Free Field Sound Detection: Partially occluded headsets enable the wearer to hear external sounds through the enclosure. The vented enclosure allows external sounds to enter the ear.

b) Audio Display Performance: Partially occluded headsets can provide high fidelity audio. The partially occluded headset is the preferred headset for many professional recording engineers.

c) Sound Discrimination: The partially occluded headset provides a sufficient amount of sound isolation to enable the wearer to hear sounds generated by the audio display in a noisy operating environment.

d) Fit/Comfort: Partially occluded headsets are designed to allow air to pass through the enclosure to ventilate heat.

e) Tactical Feasibility: Sound generated by partially occluded headsets is presented next to the wearer's ear to prevent sounds from exiting the enclosure.

f) Spatialization: Partially occluded circumaural headsets provide excellent channel separation and are recommended for listening to 3D audio.

g) Reliability: Partially occluded headsets are mechanically simple and reliable. The wearer can hear audio displayed by the headset even if it shifts position or looses direct contact with the ear.

h) Durability: The partially occluded headset can be constructed of durable materials to resist shock and impact damage.

i) Availability and Cost: Partially occluded headsets are commercially available. Some high quality headsets use expensive speaker components.

3.2.2 Disadvantages

a) Free Field Sound Detection: The headset obstructs the ear, so free field hearing sensitivity is reduced by several decibels. This interferes with the wearer's ability to detect external sounds in the environment while wearing the headset.

b) Sound Discrimination: Loud free field noises are able to pass through the enclosure and interfere with the wearer's perception of the audio signal.

c) Equipment Compatibility: Although they are not as heavy as fully occluded headsets, partially occluded headsets tend to interfere with helmets and other types of equipment worn on the head due to their size and shape.

d) Fit/Comfort: Circumaural headsets can cause discomfort with prolonged use because they compress the pinnae of the ear.

e) Tactical Feasibility: Partially occluded headsets allow sound generated by the audio display to pass through the enclosure.

f) Spatialization: Partially occluded headsets allow external sounds to reach the ear, which can interfere with perception of 3D audio.

g) Durability: Partially occluded headsets use a mesh or vented enclosure to provide air circulation. This design can be less durable than a hard shell enclosure and may potentially reduce the strength and service life of the headset.

3.3 Open Ear Supraural Acoustic Headset

Open ear headsets use an open enclosure and can provide either a supraural fit which against the wearer's ears or be helmet-mounted and worn off the wearer's ears. They provide no passive noise attenuation but can be used in conjunction with active noise reduction. Open ear headsets provide passive talk-through.

Figure 3. Telex K-99 Stinger Helmet Mounted Speaker

3.3.1 Advantages

a) Free Field Sound Detection: Open ear headsets that are positioned off the ear allow external sounds to reach the ear. This enables the wearer to detect sounds in the open field.

b) Audio Display Performance: The open ear headset can provide adequate sound quality for transmission of speech and auditory cues to the wearer.

c) Equipment Compatibility: Open ear headsets are thinner and lighter than circumaural headsets so they can be attached to or worn inside a helmet.

d) Fit/Comfort: Open ear headsets can be designed to fit lightly against the ear or slightly off the ear. These headsets are comfortable because they do not trap heat and do not compress the pinnae of the ear.

e) Durability: Helmet-mounted audio displays are protected from impact by the structure of the helmet.

f) Availability and Cost: Open ear headsets are commercially available and inexpensive.

3.3.2 Disadvantages

a) Free Field Sound Detection: Supraural open ear headsets (which are worn against the ear) partially cover the ear and can interfere with free field sound detection.

b) Audio Display Performance: Perceived sound quality can be greatly reduced if the speaker is mounted too far away from the wearer's ear. The acoustic characteristics of the helmet or enclosure can also reduce the sound quality of open ear headsets.

c) Sound Discrimination: Open ear headsets do not provide an isolated soundstage to direct sound to the ear. External sound from the free field is able to bypass the enclosure and interfere with the wearer's perception of the audio signal. For example, wind noise can degrade the signal to noise ratio of the headset.

d) Equipment Compatibility: Some types of open ear headsets are designed to attach to the wearer's helmet. Any device that is attached to the helmet cannot be used in situations when soldiers are not wearing their helmet.

e) Tactical Feasibility: Open ear headsets increase the risk of enemy detection because the open enclosure allows sound to escape.

f) Spatialization: Open ear headsets allow external sounds to reach the ear. Interference from external sounds can confound the perception of 3D audio. Open ear supraural headsets are not as effective as circumaural headsets for presenting 3D audio because they do not provide an enclosed listening area to contain and direct sound to the ear.

g) Reliability: Open ear headsets attached to the helmet can vibrate during physical activity and become misaligned to the ear. The wearer may have difficulty hearing audio information presented by the display if the speaker moves too far away from the ear.

h) Durability: Open ear headsets are built without an enclosure, which leaves the headset vulnerable to impact damage.

3.4 In-Ear Headset

In-ear headsets use a fully or partially occluding earplug and fit inside the wearer's ears. The earplug can be made of foam or plastic and can be either universal fit or custom fit to the wearer's ear canal. They provide passive noise attenuation and can be used in conjunction with active noise reduction. In-ear headsets can also provide passive or active talk through. These devices can be used to provide ballistic noise protection. A wireless version of the in-ear headset is also commercially available.

Figure 4. Invisio In-Ear Speaker

3.4.1 Advantages

a) Audio Display Performance: In-ear headsets present audio information directly to the eardrum within the ear canal. This presentation creates the perception of speech coming from inside the wearer's head. Detailed audio displayed at a very low volume can be easily perceived.

b) Sound Discrimination: In ear headsets provide an enclosed sound stage for presenting a detailed audio signal. In-ear headsets provide excellent sound quality and spatialization in even loud operational environments.

c) Equipment Compatibility: In-ear headsets tend to be the smallest and lightest type of headset. Due to their small size they do not interfere with helmets or other types of equipment worn on the head.

d) Tactical Feasibility: The earplug isolates sounds generated by the speaker to prevent detection.

e) Spatialization: In-ear occluded displays provide optimal channel separation and present a discrete signal to each ear.

f) Reliability: The in-ear headset is firmly secured in place to reduce the probability of becoming misaligned to the ear as a result of vibration or physical activity.

g) Availability and Cost: Inexpensive universal plastic or foam in-ear headsets are commercially available. Headsets that use custom ear moulds are very expensive to build because they must be made individually by an audiologist.

3.4.2 Disadvantages

a) Free Field Sound Detection: Occluded in-ear headsets interfere with verbal communications and detection of free-field sounds. The enclosure prevents external free field sounds from reaching the ear. Passive or active talk-through systems must be used to provide access to external sounds. Talk-through systems do not tend to be as effective as the unaided ear.

b) Fit/Comfort: In ear headsets cause discomfort with prolonged use because they irritate the skin in the ear canal. Hygiene is an issue of concern with any device worn inside the ear. Dirt or other debris that enters the ear canal can cause ear lacerations or inner ear infections.

c) Reliability: The wires that connect the headset to the audio source can snag and cause the headset to dislodge from the wearer's ears.

d) Durability: When not worn inside the ear, the earplug is a fragile device that can be easily contaminated or damaged and rendered unserviceable.

3.5 Bone Conduction Headset

Bone conduction headsets use an open enclosure and must remain in contact with the scull. These can either be helmet-mounted or attached to wearer's head. They provide no passive noise attenuation but can be used in conjunction with an independent, active, noise reduction system. Bone conduction headsets provide passive talk-through. They can also function as a microphone to transmit speech.

Figure 5. Temco Voiceducer Headgear HG17

3.5.1 Advantages

a) Free Field Sound Detection: These headsets do not interfere with verbal communications or the detection of sounds in the free field. Bone conduction headsets fit away from the ear, so the wearer's ears are clear to listen to sounds in the free field.

b) Audio Display Performance: Bone conduction headsets can provide high quality sound at an acceptable volume.

c) Sound Discrimination: Sound is conducted through the bones of the scull rather than through the air. Sounds generated by the bone conduction audio display can be heard over noise in the free field.

d) Equipment Compatibility: Bone conduction headsets can be worn beneath a hat or helmet. The headset can also be worn in conjunction with hearing protection or hearing enhancement systems.

e) Fit/Comfort: The flat surface of the bone conduction headset fits firmly against the wearer's head. Bone conduction headsets are comfortable to wear for long-term use because they are small and lightweight.

f) Tactical Feasibility: Bone conduction headsets transmit sounds directly to the wearer's head to prevent detection.

g) Spatialization: Bone conduction headsets can display stereo channel separation.

h) Reliability: The headset can be firmly held in place beneath a helmet. The bone conduction headset can transmit sound to the wearer in any noise condition even if the ears are obstructed with a hearing protection device.

i) Durability: The bone conduction transducer is constructed of metal. The headset can withstand vibration and shock without failure.

j) Availability and Cost: Bone conduction microphones are commercially available. These microphones tend to be quite expensive compared to conventional boom microphones.

3.5.2 Disadvantages

a) Audio Display Performance: Bone conduction headsets must be positioned in front of the listener's ear to achieve the best sound quality. Audio performance declines dramatically if the bone conduction transducer is not positioned in the optimal location.

b) Sound Discrimination: External sounds from the free field can interfere with the wearer's perception of the audio signal.

c) Spatialization: Research is required to evaluate the effectiveness of bone conduction headsets compared to acoustic headsets for displaying 3D audio using head-related transfer functions.

d) Reliability: The headset will not transmit an audio signal to the wearer if the bone conduction transducer looses contact with the wearer's head.

3.6 Audio Display Device Summary

Overall, the bone conduction headset is rated better than the other types of audio displays. The bone conduction headset has unique advantages in terms of Free Field Sound Detection, Equipment Compatibility, Fit and Comfort, Tactical Feasibility, and Durability (see Table 2). The bone conduction headset is best suited for the tasks of soldiers where comfort for prolonged use, compatibility with helmets and other equipment and durability are critically important. The bone conduction headset provides the unique advantage of enabling the wearer to simultaneously hear system-generated and free field sounds.

The fully occluded circumaural headset was rated second best overall and has unique advantages in terms of Spatialization. The occluded headset is the best system for displaying 3D audio information. The fully occluded and in-ear headsets are rated highest in terms of Audio Display Performance and Sound Discrimination. Each of these systems is capable of providing strong attenuation of external free field sounds.

The fully occluded circumaural and partially occluded headsets are rated highest in terms of Reliability. Both of these systems are designed to stay aligned to the ear and can function if direct contact is lost. The partially occluded circumaural and open ear supraural acoustic headset are reated best in terms of Availability and Cost because these systems are commercially available and are inexpensive to manufacture.

Table 3. Performance Measures for Audio Display Devices

Rating Criteria	Fully Occluded Circumaural Headset	Partially Occluded Circumaural Headset	Open Ear Supraural Acoustic Headset	In-Ear Headset	Bone Conduction Headset
Free Field Sound Detection	2	4	4	2	**7**
Audio Display Performance	**6.5**	6	4	**6.5**	4
Equipment Compatibility	3	3	4	6	**7**
Availability & Cost	6	**7**	**7**	5	5
Fit/Comfort	4	5	5	3	**7**
Tactical Feasibility	5	4	2	6	**7**
Sound Discrimination	**6**	4	3	**6**	4
Reliability	**6**	**6**	2	4	4
Durability	5	5	4	2	**6**
Spatialization	7	5	2	**6.5**	4
Total	50.5	49	37	47	**55**

4. References

BOS, J.C. and TACK, D.W., 2005. Input Device Investigation for Future Dismounted Soldier Computer Systems. CR2005-052. Toronto:ON, *Defence Research and Development Canada – Toronto*.

COLBERT, H , TACK, D.W., Bos, J.C., 2005. Radio Communication Input and Display Devices for Infantry Soldiers. CR2005-039. Toronto:ON, *Defence Research and Development Canada – Toronto*.

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(U) Audio displays are required to provide radio communications, multi−channel auditory information, and 3D audio feedback that can be perceived by soldiers in a high−noise, combat environment without decreasing the soldier's ability to detect local sounds and voices in the free field. A comparison of five types of audio displays (bone conduction, in−ear, unoccluded headset, partial and fully occluded headset) was conducted based upon existing literature, user feedback and the authors' experience. This report presents the results of that comparison. Overall, the bone conduction headset is rated better than the other types of audio displays because it has unique advantages in terms of Free Field Sound Detection, Equipment Compatibility, Fit and Comfort, Tactical Feasibility, and Durability. The bone conduction headset is best suited for the tasks of soldiers where durability, comfort, and compatibility with helmets and other equipment are critically important. The bone conduction headset provides the unique advantage of enabling the wearer to simultaneously hear system−generated and free field sounds. The fully occluded circumaural headset was rated second best overall and has unique advantages in terms of Spatialization. The occluded headset is the best system for displaying 3D audio information. The fully occluded and in−ear headsets are rated highest in terms of Audio Display Performance and Sound Discrimination. Each of these systems is capable of providing strong attenuation of external free field sounds in a high−noise environment.

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(U) Soldier Information Requirements Technology Demonstration Project; SIREQ TD; audio display; radio; communications; auditory information; 3D audio; bone conduction; bone conduction headset