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RADIO COMMUNICATIONS INPUT AND DISPLAY FOR INFANTRY SOLDIERS

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Abstract

This report describes a three-day experiment investigating input and display devices for voice communications in the context of urban section attacks. Four input/display pairs were investigated: 1) a boom microphone input device combined with an open ear speaker display, 2) an in-ear bone-conduction input device and an in-ear bone-conduction speaker display, 3) a throat microphone input device combined with a helmet-mounted speaker display and 4) a cranial bone-conduction input device with a cheek bone-conduction speaker display. The aims of the experiment were to compare the effectiveness of different input and display devices for radio communication and to identify the optimum input/display combination for intra-section infantry radios. Sixteen soldiers organized into two sections were participants in the experiment. The participants completed a series of section attacks against three enemy force soldiers in an urban environment, while communicating using each of the four systems under investigation. Each participant used each configuration twice for a total of eight section attacks per participant. Data collection included questionnaires, focus groups and HF observer assessments. Questionnaire data was collected in nine categories: Information Transfer, Mission Coordination, Fit and Comfort, Situation Awareness, Compatibility, Function, Durability, Reliability and Overall Evaluation. The data collected from the questionnaires indicated a preference for the cranial bone-conduction input device with a cheek bone-conduction speaker display, provided some design changes were incorporated to make it more compatible with the Canadian Infantry Helmet. The in-ear bone-conduction input device and speaker display and the boom microphone input device combined with an open ear speaker display were second and third choices respectively. The throat microphone input device combined with a helmet-mounted speaker display was the last choice system, and was rated unacceptable overall by more than 20% of participants for Fit and Comfort, Compatibility, Function, Durability, Reliability and Overall Evaluation.

Résumé

Le présent rapport décrit une expérience de trois jours qui a porté sur les dispositifs d'entrée et de reproduction destinés aux communications vocales dans le contexte des attaques urbaines de section. Quatre paires de dispositifs d'entrée et de reproduction ont été étudiées : 1) un dispositif d'entrée à micro-rail combiné à un haut-parleur à l'extérieur de l'oreille, 2) un dispositif d'entrée à conduction osseuse à l'intérieur de l'oreille combiné à un haut-parleur à conduction osseuse à l'intérieur de l'oreille, 3) un dispositif d'entrée à laryngophone combiné à un haut-parleur monté sur casque et 4) un dispositif d'entrée à conduction osseuse du crâne combiné à un haut-parleur à conduction osseuse de la joue. L'expérience avait pour objectifs de comparer l'efficacité de différents dispositifs d'entrée et de reproduction utilisés pour les radiocommunications ainsi que de déterminer la combinaison optimale de dispositifs d'entrée et de reproduction pour les postes radio intra-section d'infanterie. Seize soldats organisés en deux sections ont pris part à l'expérience. Les participants ont mené une série d'attaques de section contre trois soldats de forces ennemies dans un environnement urbain, tout en communiquant au moyen de chacun des quatre systèmes à l'étude. Chaque participant a utilisé chaque configuration deux fois, ce qui a donné au total huit attaques de section par participant. Les données ont été recueillies au moyen de questionnaires, de groupes de discussion et d'observations des facteurs humains. Les données des questionnaires ont été subdivisées en neuf catégories : transfert d'information, coordination de mission, ajustement et confort, connaissance de la situation, compatibilité, fonction, durabilité, fiabilité et évaluation globale. Les données tirées des questionnaires ont révélé une préférence pour le dispositif d'entrée à conduction osseuse du crâne combiné au haut-parleur à conduction osseuse de la joue, à condition que certaines modifications soient apportées pour améliorer la compatibilité avec le casque de l'infanterie canadienne. Le dispositif d'entrée à conduction osseuse à l'intérieur de l'oreille combiné au haut-parleur à conduction osseuse à l'intérieur de l'oreille et le dispositif d'entrée à micro-rail combiné au haut-parleur à l'extérieur de l'oreille ont respectivement constitué les deuxième et troisième choix. Le dispositif d'entrée à laryngophone combiné au haut-parleur monté sur casque s'est classé en dernier et a été jugé globalement inacceptable par plus de 20 % des participants pour ce qui est de l'ajustement et du confort, de la compatibilité, de la fonction, de la durabilité, de la fiabilité et de l'évaluation globale.

Executive Summary

This report describes a three-day experiment investigating input and display devices for voice communications in the context of urban section attacks. The following four input/display pairs were investigated:

1) a boom microphone input device combined with an open ear speaker display,

2) an in-ear bone-conduction input device and an in-ear bone-conduction speaker display,

3) a throat microphone input device combined with a helmet-mounted speaker display and,

4) a cranial bone-conduction input device with a cheek bone-conduction speaker display.

The aims of the experiment were to compare the effectiveness of different input and display devices for radio communication and to identify the optimum input/display combination for intra-section infantry radios. Sixteen soldiers organized into two sections were participants in the experiment. The participants completed a series of section attacks against three enemy force soldiers in an urban environment, while communicating using each of the four systems under investigation. Each participant used each configuration twice for a total of eight section attacks per participant. Data collection included questionnaires, focus groups and HF observer assessments. Questionnaire data was collected in nine categories: Information Transfer, Mission Coordination, Fit and Comfort, Situation Awareness, Compatibility, Function, Durability, Reliability and Overall Evaluation.

The results of this research indicate the following order of preference among the four systems tested: 1) Cranial microphone system, 2) In-Ear system, 3) Boom microphone system, 4) Throat microphone system. Conclusions for each system are described below:

1) Cranial System

The participants' first choice was the cranial system. Advantages of this system were mainly attributable to the fact that it had no components that covered or protruded over the ears or the face, thus it did not interfere with situation awareness or cause compatibility problems with hearing protection, gas masks or clothing. It was viewed as one of the better functioning, more durable and more reliable systems.

The major problems with the system were associated with compatibility with the Canadian Infantry Helmet. Specifically, the top panel of the system dug into the head, causing pain when the system was worn with the helmet. Small modifications to the design of the top panel to make it thinner or more flexible would alleviate this problem. Alternatively, redesign of the helmet to accommodate the top panel could be an option.

2) In-Ear System

The second most preferred system was the in-ear system. This system was considered the most comfortable, and most compatible system. It was small, light and unobtrusive.

However, durability and ruggedness were concerns. Participants felt that it might be too fragile for field use. Also the in-ear system could not be worn with ear-plugs and the design tested fit only in the right ear. Some participants found the fit more acceptable than others and in order for it to fit all soldiers properly, costly custom fitting could be required.

3) Boom Microphone System

The third place system was the boom microphone system. Participants found it functioned well and was reliable. They commented that it was comfortable, but not as comfortable as the in-ear system. They also felt it was durable, but it was not rated as durable as the cranial system.

Disadvantages of this system included compatibility concerns caused by the boom microphone. Participants felt it would be difficult to use with gas masks and winter headwear. Situation awareness was also a concern, as the earpiece covered one ear. The ability to switch the earpiece and the microphone from the right ear to the left would be an improvement.

4) Throat Microphone System

The throat microphone system was universally rated much less acceptable than the three other systems. This system was rated unacceptable overall by more than 20% of participants for Fit and Comfort, Compatibility, Function, Durability, Reliability and Overall Evaluation. Situation awareness was the only category where it was rated acceptable by more than 80% of participants on the Exit questionnaire.

Participants found the band around their throat uncomfortable and worried about the compatibility of the helmet-mounted speaker with other headwear.

The results of this study indicate that of the four input and display systems tested, the cranial system is the most preferred and effective system. If improvements were made to increase its compatibility with the Canadian Infantry Helmet, it would be a very comfortable and effective system. Other improvements could include reducing the amount of wiring and incorporating a wireless push-to-talk.

Sommaire

Le présent rapport décrit une expérience de trois jours qui a porté sur les dispositifs d'entrée et de reproduction destinés aux communications vocales dans le contexte des attaques urbaines de section. Les quatre paires suivantes de dispositifs d'entrée et de reproduction ont été étudiées :

1) un dispositif d'entrée à micro-rail combiné à un haut-parleur à l'extérieur de l'oreille,

2) un dispositif d'entrée à conduction osseuse à l'intérieur de l'oreille combiné à un haut-parleur à conduction osseuse à l'intérieur de l'oreille,

3) un dispositif d'entrée à laryngophone combiné à un haut-parleur monté sur casque et

4) un dispositif d'entrée à conduction osseuse du crâne combiné à un haut-parleur à conduction osseuse de la joue.

L'expérience avait pour objectifs de comparer l'efficacité de différents dispositifs d'entrée et de reproduction utilisés pour les radiocommunications ainsi que de déterminer la combinaison optimale de dispositifs d'entrée et de reproduction pour les postes radio intra-section d'infanterie. Seize soldats organisés en deux sections ont pris part à l'expérience. Les participants ont mené une série d'attaques de section contre trois soldats de forces ennemies dans un environnement urbain, tout en communiquant au moyen de chacun des quatre systèmes à l'étude. Chaque participant a utilisé chaque configuration deux fois, ce qui a donné au total huit attaques de section par participant. Les données ont été recueillies au moyen de questionnaires, de groupes de discussion et d'observations des facteurs humains. Les données des questionnaires ont été subdivisées en neuf catégories : transfert d'information, coordination de mission, ajustement et confort, connaissance de la situation, compatibilité, fonction, durabilité, fiabilité et évaluation globale.

Les résultats de cette recherche indiquent l'ordre de préférence suivant parmi les quatre systèmes à l'essai : 1) système à microphone crânien, 2) système à l'intérieur de l'oreille, 3) système à micro-rail, 4) système à laryngophone. Les conclusions relatives à chaque système sont exposées ci-dessous.

1) Système crânien

Le système crânien a constitué le premier choix des participants. Les avantages de ce système étaient principalement attribuables au fait qu'aucun élément ne couvrait les oreilles ou le visage ni ne passait devant, ce qui ne posait aucun obstacle à la connaissance de la situation et n'occasionnait aucun problème de compatibilité avec les protecteurs auriculaires, les masques à gaz ou les vêtements. On a jugé qu'il s'agissait de l'un des systèmes fonctionnant le mieux et offrant le plus de durabilité et de fiabilité.

Les principaux problèmes posés par ce système avaient trait à la compatibilité avec le casque de l'infanterie canadienne. Plus précisément, le panneau supérieur du système pesait contre la tête, causant de la douleur lorsque le système était utilisé avec le casque. De légères modifications en vue de rendre le panneau supérieur plus mince ou plus souple permettraient de remédier à ce problème. On pourrait aussi envisager de refaire la conception du casque afin de le rendre plus compatible avec le panneau supérieur.

2) Système à l'intérieur de l'oreille

Le système à l'intérieur de l'oreille s'est classé en deuxième position. Ce système a été jugé le plus confortable et le plus compatible. Il était petit, léger et non dérangeant.

Sa durabilité et sa robustesse ont toutefois soulevé des préoccupations. Les participants étaient d'avis qu'il était peut-être trop fragile pour s'utiliser sur le terrain. De plus, le système à l'intérieur de l'oreille ne pouvait pas se porter avec des bouchons d'oreille et la conception à l'essai ne convenait qu'à l'oreille droite. Certains participants ont trouvé l'ajustement plus acceptable que d'autres, et il se pourrait qu'un coûteux ajustement personnalisé s'impose pour que le système convienne à tous les soldats.

3) Système à micro-rail

Le système à micro-rail a représenté le troisième choix. Les participants ont jugé qu'il fonctionnait bien et qu'il était fiable. Ils ont ajouté qu'il était confortable, mais pas autant que le système à l'intérieur de l'oreille. Ils croyaient aussi qu'il était durable, bien qu'ils ne l'aient pas considéré aussi durable que le système crânien.

Les inconvénients de ce système tenaient à la compatibilité du micro-rail. Les participants étaient d'avis qu'il serait difficile à utiliser avec un masque à gaz et un système de coiffure hivernale. La connaissance de la situation soulevait aussi des préoccupations, car l'écouteur couvrait une oreille. Il serait commode de pouvoir déplacer l'écouteur et le microphone de l'oreille droite à l'oreille gauche.

4) Système à laryngophone

Le système à laryngophone a été généralement jugé beaucoup moins acceptable que les trois autres systèmes. Plus de 20 % des participants ont considéré ce système comme globalement inacceptable pour ce qui est de l'ajustement et du confort, de la compatibilité, de la fonction, de la durabilité, de la fiabilité et de l'évaluation globale. La connaissance de la situation constituait la seule catégorie pour laquelle le système a été jugé acceptable par plus de 80 % des participants sur le questionnaire de départ.

Les participants ont indiqué que la courroie entourant la gorge n'était pas confortable, et ils ont exprimé des doutes quant à la compatibilité du haut-parleur monté sur casque avec d'autres systèmes de coiffure.

Les résultats de cette étude indiquent que, parmi les quatre systèmes d'entrée et de reproduction à l'essai, le système crânien est préféré et jugé le plus efficace. Si des améliorations étaient apportées pour accroître sa compatibilité avec le casque de l'infanterie canadienne, il en résulterait un système très confortable et efficace. On pourrait aussi envisager la réduction du câblage et l'intégration d'un poussoir d'émission sans fil.

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1. Background

The Soldier Information Requirements (SIREQ) cognitive task analyses identified the abilities to transfer information and to communicate between members in a dismounted infantry Section as critical requirements for mission success. In the case of a typical execution phase of any mission, soldiers currently whisper or use hand signals, passed from person to person, during stealthy actions or use yelled voices during engagement actions. Both methods have their shortcomings: hand signals require a line of sight between the sender and receiver and good visibility, and raised voices indicate the speaker's location to the enemy, reveal intent to English or French speaking enemy, and risk intelligibility problems or the message being unheard in noisy battle conditions. To overcome these current deficiencies in intra-section communications, most soldier modernization programs have adopted an intra-section radio as part of their hardware ensemble.

Previous Work: Accepting the deficiencies in our current methods of intra-section communication, the choice of a radio system still raised a number of issues and opportunities for investigation. Previous SIREQ laboratory and field experiments have investigated the feasibility of radio communications for infantry sections in both urban and wooded environments, the effects of different radio network configurations, and the effects of combining radio voice communications with digital maps. Two lab experiments have been conducted at DRDC Toronto and two field experiments have been conducted at Fort Benning, Georgia. The experiments concluded that radio voice communication is desirable for all Section members and proved effective at improving situation awareness, command and control, and for enabling a wider dispersion of soldiers, especially at night. Dissemination and sharing of information between section members was also significantly more frequent when a radio network was present, as compared to the current no-radio condition. The experiments confirmed that a radio network that included separate assault group networks in addition to a section-wide network was a desirable network configuration to enable both intra-section and extra-section communication (Adams et. al. 2004a, 2004b, 2004c and 2004d). Thus a radio network conforming to these specifications was used in this current experiment.

Focus group and questionnaire data indicated overwhelming support for a radio system, however there were some issues raised with respect to the boom microphone and speaker headsets that were used with the radios. Participants commented that the headset was not compatible with their helmets, the boom microphone in front of the face was awkward and that the radio cabling and wiring needed to be improved. Therefore, alternative input devices and display options for radios needed to be investigated.

Current experiment: The experiment described in this report investigated different input and display devices for voice communications in the context of urban section attacks. This experiment compared the effects of the following four input/display pairs:

- A boom microphone input device combined with an open ear speaker display.
- An in-ear bone-conduction input device and an in-ear bone-conduction speaker display.
- A throat microphone input device combined with a helmet-mounted speaker display.
- A cranial bone-conduction input device with a cheek bone-conduction speaker display.

2. Aims

The following aims were pursued during this experiment:

- Compare the effectiveness of different input devices for radio communication.
- Compare the effectiveness of different display (or output) devices for radio communication.
- Identify the optimum input/display combination for intra-section infantry radios.

3. Method

This section gives an overview of the experimental method and explains the approach, data collection method, and equipment used.

3.1 Overview

The following description provides a general overview of the trial method. Further details are provided in subsequent sections.

A three-day field trial was undertaken at the McKenna MOUT site (Figure 1) in Fort Benning, Georgia on February 27, February 28 and March 1 2003. Sixteen soldiers from the 3rd battalion of the Princess Patricia Canadian Light Infantry (3PPCLI) participated in this study. On each of the first two days, a different section of eight regular force infantry soldiers undertook section attack missions against three enemy force soldiers in an urban environment.

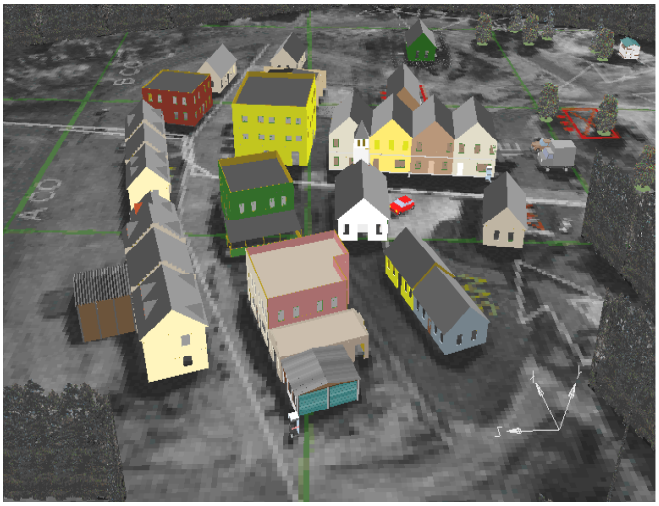


Figure 1: McKenna MOUT Site

Each participant was required to perform section attacks while wearing each of the four radio input/display configurations shown in Table 1, during daytime missions. Each participant used each configuration twice for a total of eight section attacks per participant.

Table 1: Experiment Conditions

Device	Input	Display
1) Breeze Headsets	Boom Microphone	Open Ear Speaker
2) Invisio Headset	In-Ear Bone-Conduction	In-Ear Bone-Conduction
2) K-99 Stinger	Throat Microphone	Helmet-Mounted Speaker
3) RGH-17	Cranial Bone Conduction	Cheek Bone Conduction

For any one mission, eight soldier participants worked together as an organic infantry section, comprised of two assault groups, to engage an enemy force of two soldiers occupying a defensive position in a building. Another enemy force soldier engaged one of the attacking assault groups as they manoeuvred through the village. The enemy force soldiers were not subjects in the experiment. For each attack mission, participants were required to manoeuvre through the MOUT streets, gain entry to an objective building, and clear the building by moving from room to room. Weapons used included blank firing and the SIMLAS laser target engagement system to simulate live weapons effects.

Human factors measures included subjective utility and usability measures of the radio input and display devices. Data collection included questionnaires, focus groups and HF observer assessments.

3.2 Approach

This section explains the details of the experimental procedure followed during the field trial.

3.2.1 Briefings / Training

Before the trial began, all participants were briefed on the goals, mission structure, radio input/display configurations, and protocol for the experiment. Participants were instructed in the use, installation, and operation of their SIMLAS equipment. They were also trained in the use of the radios and input/display devices and given an opportunity to practice operating the devices with other members of their section.

3.2.2 Missions

Each section performed eight missions in a single day of experimentation. Each mission comprised the following three phases:

Phase 1: Mission Briefing: Prior to the mission, the section was provided with execution orders, rules of engagement, a defined route, RV point and entry point for each assault group, and the number of enemy at the objective. Each mission was designed to employ small unit tactics to emphasize the issues of control within the section and within each assault group, stealth during the approach, and coordination during the assault. Each assault group maneuvered independently through the village to an Objective Rendezvous (ORV) prior to adopting their final

independent assault routes to the objective building. Each mission was configured to standardize the mission parameters between conditions, within the context of tactics for urban operations. See Figure 2 for an example mission.

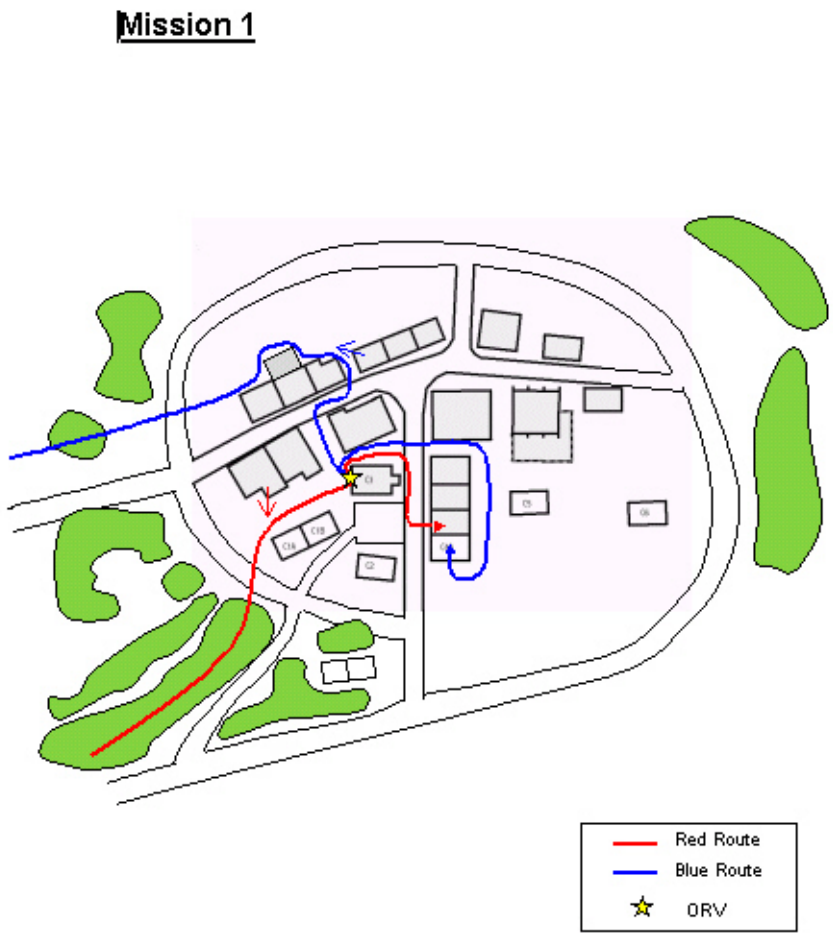


Figure 2: Example Mission

Phase 2: Mission Planning: The section was then given the opportunity to study the map of the village. Assault groups were assigned to either the red or blue approach route as shown in Figure 2. Different routes were assigned for each mission. Each section commander or assault group leader then briefed the plan through mission orders to his group as required.

Phase 3: Mission Execution: Based on the assigned orders, the section executed the mission with each participant using one of the input/display configurations in Table 1. Thus, two participants (i.e. one participant in each assault group) used each input/display configuration

during each section attack. Enemy forces were dressed in opposing force (OPFOR) dress and all participants were armed with C7A1 personal weapons. Friendly and enemy force soldiers were outfitted with SIMLAS laser target engagement systems to record weapons engagements.

Each assault group was required to move tactically with stealth along their assigned approach route. One of the assault groups was engaged enroute by a lone enemy sniper. This engagement required the assault group to delay and coordinate their movement to avoid or dispatch the sniper. This delay affected the coordination and awareness between the two assault groups.

Having maneuvered to the objective building or structure, the two assault groups began a coordinated assault on the objective. Each mission required the assault groups to enter and clear the objective building from different approaches (i.e. without line of sight between groups). This required the participants to clear rooms in the objective building by engaging and dispatching enemy soldiers as they were encountered, while being mindful of the likely location and status of the other assault group.

Phase 4: Post-Mission Measurements: Following each participant's second mission with a system, participants completed a post-mission questionnaire. Individual participant comments were expanded through interview technique. A final focus group discussion was held at the completion of all missions, on March 1, 2003.

3.3 Data Collection

Data was collected at the start of the experiment, the end of each mission, and at the end of the experiment. All questionnaires used for data collection are included in Annex 1.

3.3.1 Start of the Experiment

Participant data was collected prior to the start of the experiment to characterize the subject sample. Participants completed a questionnaire with regards to their years of infantry experience (MOC 031), rank, age and any issues with hearing loss or hearing-related injuries.

3.3.2 End of Second Mission with Each system

After the completion of each participant's second mission with a system, the following data was collected:

Task Questionnaires: Participants completed a questionnaire to assess the effect of the radio input/display configuration on the missions. The questionnaire assessed information transfer during the mission and mission co-ordination. Participants were asked to rate questionnaire items using the seven-point scale in Figure 3.

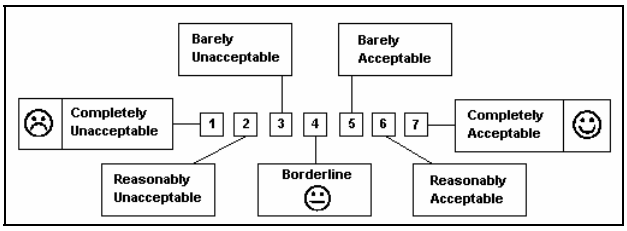


Figure 3: The Seven-Point Acceptability Scale

3.3.3 End of the Experiment

After the completion of all missions, and based on experience with all four systems, participants completed an Exit Questionnaire to compare the four systems. The questionnaire assessed fit and comfort of the input and display devices, effects on situation awareness, compatibility with clothing and equipment, function of the devices, durability, reliability and an overall system rating. Participants rated the questionnaire items using the seven-point scale in Figure 3. Following the Exit Questionnaire, a final focus group was held to discuss participant opinions and experiences regarding benefits and drawbacks of the four input/output configurations and other aspects of the experiment.

3.4 Equipment

This section describes the equipment used throughout this experiment.

3.4.1 Kenwood TK-280 Radio

All participants used a Kenwood TK-280 personal radio as shown in Figure 4. The TK-280 measures 58mm X 135mm X 34mm, weighed 460g and met military environmental specifications. It has multiple scanning features that allowed users to scan other networks while set to send on a specific network.

Figure 4: The Kenwood TK-280 radio

The TK-280 radios had four networks that were configured as follows.

Network #1 = Section Commander and 2IC only.

Network #2 = Assault Group 1 members only (i.e. four participants)

Network #3 = Assault Group 2 members only (i.e. four participants)

Network #4 = All Section members (i.e. all eight participants)

Since the Section Commander and the 2IC each led one of the two assault groups, they each had access to three possible networks. The remaining riflemen had access to two networks (i.e. their assault group and the larger section net).

3.4.2 Radio Communications Network

A digital radio communications system was developed to track and log all radio voice communications during missions. The communications network comprised a central PC server connected to four base station receivers (see Figure 5). Each participant's radio was digitally encoded so it could be recognized by the central PC server.

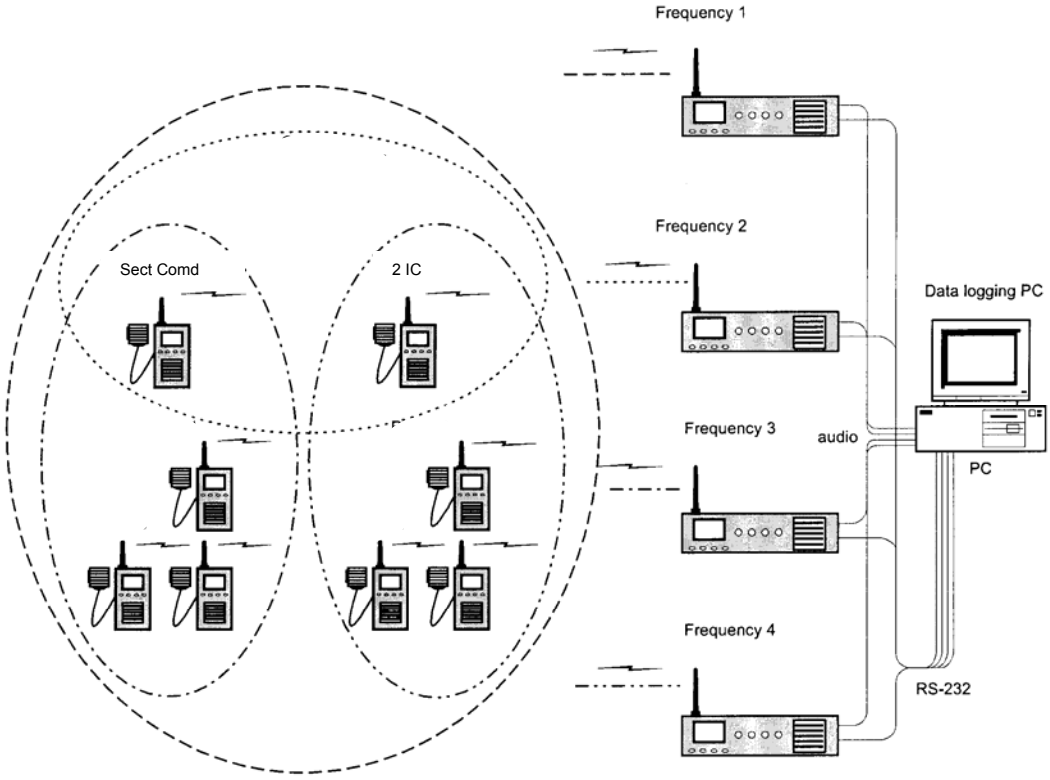


Figure 5: Communications Network

To talk to other members of a network, a participant selected the network, depressed the push-to-talk button and spoke into his assigned radio input device. The appropriate network base station receiver then detected and transferred the voice communication to one of four soundcards resident in the PC server. The server logged the time, sender identification, network (thereby identifying the list of listeners), and stored a digital record of the communication in a WAV file.

3.4.3 Input and Display Devices

This section describes the specific input and display devices that were used for each condition.

Condition 1: Boom Microphone and Open Ear Speaker: Breeze Headsets

Breeze headsets were used for the boom microphone and open ear speaker condition. See Figure 6.

Figure 6: Breeze Headset

The Breeze headset is a light-weight, high activity headset designed for use in active environments. It features a flexible electret boom microphone and a wired, finger-ring push-to-talk. The single speaker display is positioned over the left ear, partially obstructing free field hearing in that ear. It can be worn with a helmet. In this report, this system is referred to as the "boom microphone system".

Condition 2: In-Ear Bone-Conduction Input and Display: Invisio Headset

Invisio Headsets were used for the in-ear bone-conduction input and display condition. See Figure 7.

Figure 7: Invisio Headset

Invisio is an in-ear microphone/loudspeaker designed to work in noisy environments. It was used with a lapel clip on push-to-talk device. Invisio works by picking up skull vibrations generated by the user's speech through the jawbone. It uses a noise-cancelling microphone to pick up voice vibrations, but minimizes the disturbance of ambient noise. In this report, this device is referred to as the "in-ear system".

Condition 3: Throat Microphone and Helmet-Mounted Speaker: K-99 Stinger

The K-99 Stinger was used for the throat microphone and helmet-mounted speaker condition. See Figure 8.

Figure 8: K-99 Stinger

The K-99 Stinger was designed for use in high noise environments such as urban warfare scenarios. The K-99 stinger is waterproof and weighs 185g. For the purposes of this experiment it was used in combination with a single helmet-mounted speaker. A wired finger-ring push-to-talk was used. In this report, this device is referred to as the "throat microphone system".

Condition 4: Cranial Bone-Conduction Input and Jaw Bone-Conduction Display: Cranial RGH-17

The cranial RGH-17 was used for the cranial bone-conduction input and cheek bone-conduction display condition. See Figure 9.

Figure 9: The RGH-17 Cranial Headgear

The RGH-17 cranial headgear uses dual bone conduction transducers to provide an audio display without blocking the ears and voice input without placing a device near the mouth. The headgear was designed to fit under helmets. The top of the head cranial conduction microphone makes it possible to wear with gas masks or other facemasks. A wired finger-ring push-to-talk was used. In this report, this device is referred to as the "cranial system".

4. Statistical Analyses

A complete-block, repeated-measures design was used (see Table 2). Each participant completed a total of eight missions with his section. In each mission he used one of the four radio input/display configurations under investigation. Thus each participant used each configuration twice and task questionnaire data were collected following the second mission. The order of configurations was balanced between participants. Missions (i.e. approach routes, sniper engagements, etc.) were randomized across all conditions. A Friedman ANOVA was undertaken for all questionnaire data. Differences are identified at $p \leq 0.05$.

Table 2: Sample Size

Device	Sample Size
1) Breeze Headsets (x2)	16
2) Invisio Headset (x2)	16
3) K-99 Stinger (x2)	16
4) RGH-17 (x2)	16

5. Results

This section describes the results of participant information data collection, task questionnaires, exit questionnaires, and focus groups.

5.1 Participants

A total of 16 soldiers from the 3rd battalion of the Princess Patricia Canadian Light Infantry (3PPCLI) in Edmonton, Alberta participated in this study. Two Sergeants, One Master Corporal, three Corporals and ten Privates participated. The participants ranged in age from 19 to 34 and had an average age of 24.8 years. They had spent from 1 to 15 years in Regular Force service with an average of 4.7 years. Two participants reported some hearing loss, and one participant reported problems with continuous ringing in both ears.

5.2 Questionnaire Data

Task and exit questionnaires required participants to rate the different input and display systems using the seven-point scale in Figure 3. Significant differences are identified at $p < 0.05$. Items where more than 20% of participants rated a system as unacceptable (i.e. < 4 on the seven-point scale) are highlighted with shading in the tables.

5.2.1 Information Transfer

In the Task Questionnaire participants were required to rate the performance of each input and display system for transferring information during the mission. Since the information transfer questions were mission specific, there were no information transfer questions on the Exit Questionnaire.

Significant differences and percentage of respondents who marked each question unacceptable on the seven-point scale are shown in Table 3.

Table 3: Task Questionnaire--Information Transfer

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Timeliness for initiating comms	mean ± s.d	5.3 ± 0.9	5.2 ± 1.2	5.3 ± 0.6	5.6 ± 0.9	$\chi^2(16,3)=1.96$ $p < 0.58110$	None
	% unacceptable	6.3%	6.3%	0%	0%		
Ease of information transfer	mean ± s.d	5.6 ± 0.7	5.7 ± 0.9	5.3 ± 0.6	5.8 ± 0.8	$\chi^2(16,3)=6.15$ $p < 0.10447$	None
	% unacceptable	0%	0%	0%	0%		
Overall Ability to Transfer Information	mean ± s.d	5.5 ± 0.7	5.6 ± 0.9	5.4 ± 0.5	5.9 ± 0.8	$\chi^2(16,3)=4.06$ $p <0.25480$	None
	% unacceptable	0%	0%	0%	0%		

There were no significant differences in all categories for Information Transfer. There were also no questionnaire items in this category where more than 20% of participants rated a system as unacceptable. In the focus group, participants indicated that all four systems tested were acceptable for transferring information and that they were generally successful in transmitting their intended messages.

5.2.2 Mission Coordination

In the Task Questionnaire participants were required to rate the performance of the four input and display systems for mission coordination. Since the mission coordination questions were mission specific, there were no information transfer or mission coordination questions on the Exit Questionnaire.

Significant differences and percentage of respondents who marked each question unacceptable on the seven-point scale are indicated in Table 4.

Table 4: Task Questionnaire --Mission Coordination

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Coordination of movement	mean ± s.d	5.2 ± 1.4	5.3 ± 1.0	5.3 ± 1.0	5.4 ± 1.4	$\chi 2(16,3)=1.71$ $p < 0.63471$	None
	% unacceptable	6.3%	6.3%	6.3%	6.3%		
Coordination of fire	mean ± s.d	5.7 ± 0.8	5.3 ± 1.5	5.3 ± 1.0	5.5 ± 1.5	$\chi 2(16,3)=2.58$ $p < 0.46163$	None
	% unacceptable	0%	6.3%	6.3%	6.3%		
Coordination of action	mean ± s.d	5.8 ± 0.7	5.3 ± 1.4	5.3 ± 0.9	5.5 ± 1.2	$\chi 2(16,3)=6.37$ $p < 0.09502$	None
	% unacceptable	0%	6.3%	0%	6.3%		
Sharing information	mean ± s.d	5.6 ± 0.6	5.2 ± 1.5	5.5 ± 0.9	5.7 ± 1.5	$\chi 2(16,3)=4.31$ $p < 0.22964$	None
	% unacceptable	0%	6.3%	0%	6.3%		
Ability to maintain mission tempo	mean ± s.d	5.6 ± 0.9	5.5 ± 1.0	5.4 ± 0.8	5.8 ± 0.8	$\chi 2(16,3)=5.13$ $p < 0.16224$	None
	% unacceptable	0%	6.3%	0%	0%		
Ability to meet mission timings	mean ± s.d	5.6 ± 1.0	5.8 ± 1.0	5.4 ± 0.9	5.7 ± 0.9	$\chi 2(16,3)=1.98$ $p < 0.57645$	None
	% unacceptable	0%	0%	0%	0%		
Overall Effectiveness of Mission Coordination	mean ± s.d	5.8 ± 0.8	5.6 ± 0.8	5.3 ± 0.9	5.9 ± 1.0	$\chi 2(16,3)=5.97$ $p < 0.11316$	None
	% unacceptable	0%	0%	0%	0%		

There were no significant differences in all categories for Mission Coordination. There were also no questionnaire items in this category where more than 20% of participants rated a system as unacceptable. Participants commented that all systems functioned to a level that allowed them to perform their missions successfully.

5.2.3 Fit and Comfort

In the Exit Questionnaire, participants were required to rate the fit and comfort of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven-point scale are shown in Table 5.

Table 5: Exit Questionnaire—Fit and Comfort

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Fit of Speaker	mean ± s.d	5.2 ± 1.0	5.6 ± 1.6	3.1 ± 1.4	5.9 ± 1.5	$\chi^2(16,3)=22.96$ $p < 0.00004$	1,2,4>3
	% unacceptable	6.3%	6.3%	56.3%	6.3%		
Comfort of Speaker	mean ± s.d	5.6 ± 1.3	5.2 ± 1.7	3.8 ± 1.7	5.4 ± 1.6	$\chi^2(16,3)=9.70$ $p < 0.02125$	1,2,4>3
	% unacceptable	6.3%	18.8%	37.5%	12.5%		
Fit of Headset	mean ± s.d	4.8 ± 1.5	5.7 ± 1.6	3.1 ± 1.5	5.6 ± 1.6	$\chi^2(16,3)=23.67$ $p < 0.00003$	1,2,4>3
	% unacceptable	18.8%	6.3%	56.3%	12.5%		
Comfort of Headset	mean ± s.d	5.0 ± 1.8	5.4 ± 2.0	4.1 ± 1.6	5.2 ± 1.8	$\chi^2(16,3)=7.79$ $p < 0.05054$	None
	% unacceptable	18.8%	18.8%	31.3%	18.8%		
Ability to Adjust Headset	mean ± s.d	4.4 ± 1.7	5.7 ± 1.5	3.7 ± 1.9	5.1 ± 1.7	$\chi^2(16,3)=12.54$ $p < 0.00574$	2>1,3 4>3
	% unacceptable	18.8%	6.3%	50.0%	18.8%		
Fit of Microphone	mean ± s.d	5.6 ± 1.0	6.2 ± 1.0	4.9 ± 1.7	5.9 ± 1.3	$\chi^2(16,3)=9.81$ $p < 0.02020$	2,4>3
	% unacceptable	0%	0%	25.0%	6.3%		
Comfort of Microphone	mean ± s.d	5.8 ± 1.0	6.2 ± 1.2	4.8 ± 1.8	5.5 ± 1.8	$\chi^2(16,3)=8.93$ $p < 0.03029$	2>3
	% unacceptable	0%	6.3%	25.0%	18.8%		
Ability to Adjust Microphone Position	mean ± s.d	6.1 ± 0.7	5.4 ± 1.7	4.7 ± 1.7	4.8 ± 1.8	$\chi^2(16,3)=10.06$ $p < 0.01805$	1>3,4
	% unacceptable	0%	6.3%	25.0%	25.0%		
Restriction of Movement	mean ± s.d	5.4 ± 1.6	6.3 ± 0.9	4.6 ± 1.5	6.0 ± 1.1	$\chi^2(16,3)=17.69$ $p < 0.00051$	2,4>3
	% unacceptable	0%	0%	18.8%	6.3%		

Table 5: Exit Questionnaire—Fit and Comfort (Cont.)

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Weight	mean ± s.d	5.9 ± 0.9	6.7 ± 0.5	5.3 ± 1.4	6.1 ± 0.9	$\chi^2(16,3)=20.30$ $p < 0.00015$	2>1,3 1,4>3
	% unacceptable	0%	0%	6.3%	0%		
Cabling	mean ± s.d	4.8 ± 1.4	5.9 ± 1.4	3.9 ± 1.7	5.8 ± 1.0	$\chi^2(16,3)=21.43$ $p < 0.00009$	2,4>1,3
	% unacceptable	31.3%	6.3%	25.0%	0%		
Size	mean ± s.d	5.4 ± 1.3	6.7 ± 0.5	4.8 ± 1.7	5.7 ± 1.1	$\chi^2(16,3)=20.07$ $p < 0.00016$	2>1,3,4 4>3
	% unacceptable	6.3%	0%	12.5%	6.3%		
Overall Fit and Comfort	mean ± s.d	5.3 ± 1.3	5.8 ± 1.6	3.8 ± 1.6	5.6 ± 1.4	$\chi^2(16,3)=17.76$ $p < 0.00049$	1,2,4>3
	% unacceptable	12.5%	12.5%	37.5%	12.5%		

All three other systems were rated significantly more acceptable than the throat microphone system for "Fit of Speaker", "Comfort of Speaker", "Fit of Headset", and "Overall Fit and Comfort". For "Ability to Adjust Headset", the in-ear system was rated significantly more acceptable than both the boom microphone system and the throat microphone system. Also, the cranial system was rated significantly more acceptable than the throat microphone system. For "Fit of Microphone" the in-ear system and the cranial system were rated significantly more acceptable than the throat microphone system. For "Comfort of Microphone" the in-ear system was rated significantly more acceptable than the throat microphone system. For "Ability to Adjust Microphone Position" the boom microphone system was rated significantly more acceptable than both the throat microphone system and the cranial system. For "Restriction of Movement", the in-ear system and the cranial system were rated significantly more acceptable than the throat microphone system. For "Weight", the in-ear system was rated significantly more acceptable than the boom microphone system and the throat microphone system. Also, the boom microphone system and the cranial system were rated significantly more acceptable than the throat microphone system. For "Cabling", the in-ear system and the cranial system were rated significantly more acceptable than both the boom microphone system and the throat microphone system.

The throat microphone system was rated unacceptable by more than 20% of participants in all Fit and Comfort categories, except "Restriction of Movement" and "Weight". The boom microphone was rated unacceptable by more than 20% of participants for "Cabling" and the cranial system was rated unacceptable by more than 20% of participants for "Ability to Adjust Microphone Position".

Comments from the focus group and questionnaires indicate that the boom microphone system was well-liked overall for fit. Participants found that it fit under the helmet, however they suggested that that the headset needed to be more adjustable, especially the bar at the back of the

head. Participants felt that cabling was a problem with the cables running to the headset, the radio and the push-to-talk becoming tangled and disconnecting.

Some participants commented on comfort problems with the in-ear system. Some found the earpiece caused a painful pressure point in the ear. One participant commented that since some cartilage in his ears had been broken, it was impossible to insert the in-ear system into his ear. There were also some comments with regards to cabling. Participants said that wires became snagged during the assault causing the in-ear system to be yanked out of the ear

There were several comfort issues raised in the focus groups with regards to the throat microphone and helmet mounted speaker system. Participants found the throat strap irritated the skin, caused perspiration, and interfered with breathing. Some found the strap itchy once they started to sweat. Others commented that the strap had to be uncomfortably tight in order for the system to work properly. There were comments that the microphone did not stay in the proper position. In general participants commented that they did not like having the strap on their throats.

Participants also commented on problems with the helmet-mounted speaker. They found the speaker did not fit well on their helmets and flopped around during the assault. They also commented that the speaker wasn't close enough to the ear.

The cranial system also had some comfort issues raised in the focus groups. Participants found it did not fit well under their helmets and it dug into the head when the helmet was worn. Participants commented that the top disc needed to be thinner and the ability to adjust the back bar would be desirable.

5.2.4 Situation Awareness

In the Exit Questionnaire, participants were required to rate their situation awareness while using each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven point scale are shown in Table 6.

Table 6: Exit Questionnaire—Situation Awareness

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Ability to Hear Voices in the Surrounding Environment	mean ± s.d	5.4± 0.8	5.1 ± 1.7	5.0 ± 1.4	6.5 ± 0.6	$\chi^2(16,3)=16.73$ $p < 0.00080$	4>1,2,3
	% unacceptable	0%	18.8%	18.8%	0%		
Ability to Hear Other sounds in the surrounding Environment	mean ± s.d	5.6 ± 0.8	5.0 ± 1.6	4.9 ± 1.6	6.5 ± 0.7	$\chi^2(16,3)=19.64$ $p < 0.00020$	4>1,2,3
	% unacceptable	0%	18.8%	18.8%	0%		
Ability to Speak Locally (not through system)	mean ± s.d	5.7 ± 1.4	6.3 ± 0.4	5.4 ± 1.5	6.4 ± 0.6	$\chi^2(16,3)=19.97$ $p < 0.00470$	2,4>3
	% unacceptable	6.3%	0%	12.5%	0%		
Overall Ability to Maintain Situation Awareness of Sounds	mean ± s.d	5.5 ± 1.2	5.5 ± 1.0	5.0 ± 1.3	6.5 ± 0.6	$\chi^2(16,3)=15.13$ $p < 0.00171$	4>1,2,3
	% unacceptable	6.3%	0%	18.8%	0%		

The cranial system was rated significantly more acceptable than the other three systems for "Ability to Hear Voices in the Surrounding Environment", "Ability to Hear other Sounds in the Environment" and "Overall Ability to Maintain Situation Awareness of Sounds". The cranial system and the In-Ear system were both rated significantly better than the boom microphone system and the throat microphone system for "Ability to Speak Locally".

There were no items where more than 20% of participants rated a system unacceptable.

Participants commented that there were no situation awareness issues with the boom microphone system, throat microphone system or cranial system. Most participants commented that the in-ear system also did not interfere with situation awareness, but some commented that they experienced an echo with the system.

5.2.5 Compatibility

In the Exit Questionnaire, participants were required to rate the compatibility of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven point scale are shown in Table 7.

Table 7: Exit Questionnaire—Compatibility

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Compatibility with Clothing	mean ± s.d	4.9 ± 1.2	5.9 ± 1.2	4.7 ± 1.6	5.6 ± 1.2	$\chi^2(16,3)=26.09$ $p < 0.00001$	2,4>1,3
	% unacceptable	15.6%	6.3%	28.1%	9.4%		
Compatibility with Equipment	mean ± s.d	4.8 ± 1.4	5.9 ± 1.3	4.4 ± 1.8	5.5 ± 1.3	$\chi^2(16,3)=25.72$ $p < 0.00001$	2>1,3 4>3
	% unacceptable	21.9%	6.3%	37.5%	9.4%		
Compatibility with Helmet	mean ± s.d	4.7 ± 1.6	6.4 ± 0.9	3.3 ± 1.9	4.0 ± 2.1	$\chi^2(16,3)=25.11$ $p < 0.00001$	2>1,3,4 1>3
	% unacceptable	21.9%	0%	53.1%	40.6%		
Overall Compatibility	mean ± s.d	4.9 ± 1.4	6.1 ± 1.0	4.0 ± 1.6	5.2 ± 1.1	$\chi^2(16,3)=23.32$ $p < 0.00003$	2>1,3,4 1,4>3
	% unacceptable	18.8%	0%	43.8%	9.4%		

The in-ear system and the cranial system were rated significantly more acceptable than both the boom microphone system and the throat microphone system for "Compatibility with Clothing". For "Compatibility with Equipment", the in-ear system was rated significantly more acceptable than both the boom microphone system and the throat microphone system. The cranial system was rated more acceptable than the throat microphone system only. For "Compatibility with Helmet", the In-Ear system was rated significantly more acceptable than all three other systems. Also the boom microphone system was rated significantly more acceptable than throat microphone system. For "Overall Compatibility", the In-Ear system was rated significantly more acceptable than all three other systems. Also both the boom microphone system and the cranial system were rated significantly more acceptable than throat microphone system.

More than 20% of participants rated the boom microphone unacceptable for "Compatibility with Equipment" and "Compatibility with Helmet". The throat microphone was rated unacceptable by more than 20% of participants in all compatibility categories. Also, the cranial system was rated unacceptable for "Compatibility with Helmet" by more than 20% of participants on both questionnaires.

Participants commented that compatibility problems existed for using the boom microphone with some clothing and equipment, for example a gas mask. Participants also commented on cabling compatibility with clothing since the cables needed to be routed inside the shirt. Sometimes the cables disconnected, and it was difficult to find the disconnection under the shirt. In general participants didn't like the ring-finger push-to-talk. Some suggested a wireless push-to-talk to relieve some of the cabling compatibility issues. Participants commented that earpieces should be provided for both ears so one could alternate if necessary.

For the in-ear system, most compatibility related comments concerned problems with the push-to-talk used. Some commented that they couldn't find a good place to put the push-to-talk. Participants found the lapel button push-to-talk was sometimes activated by mistake. All in the focus group felt a wireless push-to-talk would be preferable. Like the boom microphone system, participants commented that earpieces should be provided for both ears.

For the throat microphone and helmet-mounted speaker, participants commented on compatibility issues with the throat microphone strap and winter wear which may cover the neck. There were also concerns that with the speaker attached to the helmet, the system would be incompatible for times when the helmet is not worn.

For the cranial headset, participants commented that compatibility with the helmet was the biggest issue. Some participants also commented that there could be compatibility issues with winter headwear as well.

5.2.6 Function

In the Exit Questionnaire, participants were required to rate the functionality of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven-point scale are shown in Table 8.

Table 8: Exit Questionnaire—Function

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Clarity of Speaker Sound	mean ± s.d	5.7 ± 0.7	6.1 ± 0.8	4.1 ± 1.4	6.3 ± 0.8	$\chi^2(16,3)=27.63$ $p < 0.00000$	1,2,4>3
	% unacceptable	0%	0%	37.5%	0%		
Sensitivity of Microphone	mean ± s.d	5.7 ± 0.4	5.9 ± 1.0	4.4 ± 1.6	6.3 ± 0.5	$\chi^2(16,3)=24.10$ $p < 0.00002$	1,2,4>3
	% unacceptable	0%	0%	25.0%	0%		
Ease of Microphone Use	mean ± s.d	5.9 ± 0.6	6.3 ± 0.7	5.1 ± 1.7	6.4 ± 0.7	$\chi^2(16,3)=13.24$ $p < 0.00415$	1,2,4>3
	% unacceptable	0%	0%	18.0%	0%		
Ease of Operation of Push-to-Talk	mean ± s.d	5.8 ± 0.9	5.5 ± 1.7	4.8 ± 2.0	6.0 ± 0.7	$\chi^2(16,3)=2.68$ $p < 0.44370$	None
	% unacceptable	0%	18.8%	25.0%	0%		
Tactical Feasibility	mean ± s.d	5.4 ± 1.2	6.4 ± 0.6	4.3 ± 1.4	6.5 ± 0.5	$\chi^2(16,3)=29.45$ $p < 0.00000$	2,4>1,3 1>3
	% unacceptable	12.5%	0%	25.0%	0%		
Overall Function of System	mean ± s.d	5.6 ± 0.7	5.9 ± 0.9	4.3 ± 1.4	6.4 ± 0.7	$\chi^2(16,3)=28.55$ $p < 0.00000$	4>1,3 1,2>3
	% unacceptable	0%	0%	25.0%	0%		

All three other systems were rated significantly more acceptable than the throat microphone system for "Clarity of Speaker Sound", "Sensitivity of Microphone", "Ease of Microphone Use", "Tactical Feasibility" and "Overall Function of System". Additionally, both the cranial and the in-ear system were rated significantly more acceptable than the boom microphone system for "Tactical Feasibility". Also, the cranial system was rated significantly more acceptable than the boom microphone system for "Overall Function of the System".

The throat microphone was rated unacceptable by more than 20% of participants for all but one of the Function items. "Clarity of Speaker Sound", "Sensitivity of Microphone", "Ease of Operation of Push-To-Talk", "Tactical Feasibility" and "Overall Function of System" all received unacceptable ratings by more than 20% of participants.

Participants commented that there were no problems with function or clarity with boom microphone system.

With the in-ear system, some participants found it did not send well for them. Some participants commented that it was easy to use, because it was so small and they almost forgot it was there.

Some participants commented that the throat microphone resulted in raspy audio, and that the sound was especially poor if the microphone started to hang away from the neck. As for the helmet-mounted speaker, participants said it would have functioned better if it were closer to the ear.

With the cranial system, most participants commented that it had excellent clear sound quality. It also had the advantage of being usable in conjunction with hearing protection

5.2.7 Durability

In the Exit Questionnaire, participants were required to rate the durability of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven point scale are shown in Table 9.

Table 9: Exit Questionnaire—Durability

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Durability of Headset	mean ± s.d	5.1 ± 1.6	5.4 ± 1.6	4.0 ± 1.7	6.0 ± 1.0	$\chi^2(16,3)=12.08$ $p < 0.00712$	1,2,4>3
	% unacceptable	18.8%	6.3%	31.3%	0%		
Durability of Microphone	mean ± s.d	4.9 ± 1.5	5.4 ± 1.6	4.4 ± 1.6	5.9 ± 1.1	$\chi^2(16,3)=13.67$ $p < 0.00339$	2>3 4>1,3
	% unacceptable	18.8%	6.3%	25.0%	0%		
Overall Durability	mean ± s.d	5.0 ± 1.5	5.4 ± 1.6	4.4 ± 1.3	5.9 ± 1.1	$\chi^2(16,3)=15.19$ $p < 0.00166$	4>1,3 2>3
	% unacceptable	18.8%	6.3%	25.0%	0%		

All other systems were rated significantly better than the throat microphone system for "Durability of Headset".

However, for "Durability of Microphone", only the cranial and in-ear systems, and not the boom microphone system, were rated significantly better than the throat microphone system. Additionally, the cranial system was rated significantly better than the boom microphone system.

For "Overall Durability", the cranial system was rated significantly better than the boom microphone and the throat microphone systems. The in-ear system was rated significantly better than the throat microphone system only.

More than 20% of participants rated the durability of the headset (helmet-mounted speaker) for the throat microphone condition as unacceptable. Additionally, "durability of the microphone" and "Overall durability" were rated as unacceptable by more than 20% of participants for the throat microphone/helmet mounted speaker condition. There were no other items with more than 20% unacceptable ratings.

For the boom microphone, participants commented that the durability was acceptable. Although some felt that the headset wire would weaken and break with use.

For the in-ear system, durability-related comments included concerns about the fragility of the wire between the push-to-talk and the headset. Participants felt it would likely break with prolonged use.

There were durability concerns with the throat microphone strap. Participants commented that they thought it would deteriorate quickly due to the effects of mud, sweat, sunblock, and insect repellent used on the neck.

For the cranial headset, participants commented that the durability of the cabling was a weak point. Participants also commented that the finger push-to-talk was not as solid as the one used for the boom microphone headset. However overall, they commented that it was a very solid unit.

5.2.8 Reliability

In the Exit Questionnaire, participants were required to rate the reliability of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven point scale are shown in Table 10.

Table 10: Exit Questionnaire—Reliability

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Reliability of Push-to-Talk	mean ± s.d	5.4 ± 0.9	5.4 ± 1.1	4.8 ± 1.4	5.4 ± 0.9	$\chi^2(16,3)=8.33$ $p < 0.03960$	4>3
	% unacceptable	0%	6.3%	18.8%	0%		
Reliability of Microphone	mean ± s.d	5.6 ± 1.3	5.6 ± 1.1	4.6 ± 1.7	6.1 ± 0.9	$\chi^2(16,3)=8.22$ $p < 0.04162$	1,2,4>3
	% unacceptable	6.3%	6.3%	31.3%	0%		
Reliability of Speaker	mean ± s.d	5.6 ± 1.3	6.1 ± 1.1	3.6 ± 1.9	6.2 ± 1.0	$\chi^2(16,3)=23.04$ $p < 0.00004$	1,2,4>3
	% unacceptable	6.3%	0%	50.0%	0%		
Overall Reliability of Entire System	mean ± s.d	5.7 ± 1.0	5.6 ± 1.3	4.2 ± 1.3	5.9 ± 0.9	$\chi^2(16,3)=17.63$ $p < 0.00053$	1,2,4>3
	% unacceptable	6.3%	6.3%	37.5%	0%		

The throat microphone was rated significantly less acceptable than all three other systems for three items: "Reliability of Microphone", "Reliability of Speaker" and "Overall Reliability of Entire System". For "Reliability of Push-To-Talk" only the cranial system was rated significantly better than the throat microphone system.

More than 20% unacceptable ratings were observed for "Reliability of Microphone", "Reliability of Speaker" and "Overall Reliability of Entire System" for the throat microphone system only.

Overall, participants made few comments related to reliability. Reliability issues with the boom microphone system included the push-to-talk becoming disconnected, so the system wouldn't send.

The in-ear system was considered reliable however, some commented that if the system were custom moulded for the individual's ear, the sound quality would improve.

5.2.9 Overall System Rating

In the Exit Questionnaire, participants were required to rate the compatibility of each of the four input/display systems. Significant differences and percentage of respondents who marked each question unacceptable on the seven-point scale are shown in Table 11.

Table 11: Exit Questionnaire—Overall System Rating

		Input and Display Device				Chi Squared and p values	Significant Differences
		1. Boom Mic	2. In-Ear	3. Throat	4. Cranial		
Overall System Rating	mean ± s.d	5.2 ± 1.1	5.7 ± 1.2	3.5 ± 1.4	6.1 ± 0.9	$\chi 2(16,3)=25.58$ $p < 0.00001$	1,2,4>3
	% unacceptable	6.3%	6.3%	43.8%	0%		

The only significant differences were that the boom microphone, the cranial system and the in-ear system were all rated significantly better than the throat microphone system. The only system with a more than 20% unacceptable rating for "Overall System Rating" was the throat microphone system (43.8%).

5.2.10 Summary

At the end of the focus group, the 16 participant soldiers were first asked which headset they preferred, of the four choices presented. They were then asked to vote again assuming that the modifications they recommended had been made to the headsets. The results are presented in Table 12.

Table 12: Focus Group Poll Results

	Boom Mic	In-Ear	Throat	Cranial
Which system did you prefer?	1 (6.3%)	8 (50.0%)	0 (0.0%)	7 43.8%)
If recommended modifications were made, which system would you prefer?	0 (0.0%)	5 (31.3%)	0 (0.0%)	11 (68.8%)

The focus group poll indicated that given the existing configurations, there was a slight preference for the in-ear system. However, if changes were made to improve the comfort and compatibility of the cranial system, it would be the preferred system.

6. Conclusions

This section provides a summary of the major results of this experiment, and makes final recommendations.

6.1 Summary

Table 13 summarizes the results of this study for the "Overall Effectiveness" category in each of the nine questionnaire sections.

Table 13: Summary of "Overall Effectiveness" Results

Category	Questionnaire	Significant Differences	More than 20% Unacceptable
Information Transfer	Task	None	None
Mission Coordination	Task	None	None
Fit and Comfort	Exit	All Other Systems > Throat Microphone System	Throat Microphone System (37.5%)
Situation Awareness	Exit	Cranial System > All Other Systems	None
Compatibility	Exit	In-Ear System > All Other Systems Boom Microphone System and Cranial System > Throat Microphone System	Throat Microphone System (43.8%)
Function	Exit	All Other Systems > Throat Microphone System Cranial System > Boom Microphone System	Throat Microphone System (25.0%)
Durability	Exit	Cranial System > Boom Microphone System and Throat Microphone System In-Ear System > Throat Microphone System	Throat Microphone System (25.0%)
Reliability	Exit	All Other Systems > Throat Microphone System	Throat Microphone System (37.5%)
Overall	Exit	All Other Systems > Throat Microphone	Throat Microphone System (43.8%)

Participants indicated a preference for the cranial bone-conduction input device with a cheek bone-conduction speaker display, provided some design changes were incorporated to make it more compatible with the Canadian Infantry Helmet. The in-ear bone-conduction input device and an in-ear bone-conduction speaker display and the boom microphone input device combined with an open ear speaker display were second and third choices respectively.

Findings for each of the systems are provided below, ordered by participant preference: 1) Cranial microphone system, 2) In-Ear system, 3) Boom microphone system, 4) Throat microphone system.

1) Cranial System

The participants' first choice was the cranial system. Advantages of this system were mainly attributable to the fact that it had no components that covered or protruded over the ears or the face, thus it did not interfere with free field visual or auditory situation awareness or cause compatibility problems with hearing protection, gas masks or clothing. It was viewed as one of the better functioning, more durable and more reliable systems.

The major problems with the system were associated with compatibility with the Canadian Infantry Helmet. Specifically, the top panel of the system dug into the head, causing pressure point discomfort when the system was worn with the helmet. Small modifications to the design of the top panel to make it thinner or more flexible would alleviate this problem. Alternatively, redesign of the helmet to accommodate the top panel could be an option.

2) In-Ear System

The second most preferred system was the in-ear system. This system was considered the most comfortable and most compatible system. It was small, light and unobtrusive.

However, durability and ruggedness were concerns. Participants felt that it might be too fragile for field use. Also the in-ear system could not be worn with ear-plugs and the design tested fit only in the right ear. Some participants found the fit more acceptable than others suggesting that custom fitting may be required to achieve a comfortable fit for all soldiers.

3) Boom Microphone System

The third-place system was the boom microphone system. Participants found it functioned well and was reliable. They commented that it was comfortable, but not as comfortable as the in-ear system. They also felt it was durable, but it was not rated as durable as the cranial system.

Disadvantages of this system included compatibility concerns caused by the boom microphone. Participants felt it would be difficult to use with gas masks and winter headwear. Auditory situation awareness was also a concern, as the earpiece covered one ear. The ability to switch the earpiece and the microphone from the right ear to the left would be an improvement.

4) Throat Microphone System

The throat microphone system was universally rated much less acceptable than the three other systems. This system was rated unacceptable overall by more than 20% of participants for Fit and Comfort, Compatibility, Function, Durability, Reliability and the Overall Evaluation. Situation awareness was the only category where it was rated acceptable by more than 80% of participants on the Exit Questionnaire.

Participants found the band around their throat uncomfortable and they noted concerns with the compatibility of the helmet-mounted speaker with other headwear.

6.2 Recommendations

The results of this study indicate that, of the four input and display systems tested, the cranial system is the most preferred and effective system. If improvements were made to increase its compatibility with the Canadian Infantry Helmet, it would be a very comfortable and effective system. Other improvements could include reducing the wiring and incorporating a wireless push-to-talk.

7. References

A. Adams, B., Tack, D., and Sartori, J. (2004a) Evaluation of Radio Communications in Dismounted Infantry Sections. Draft Report submitted to Defence Research and Development Canada—Toronto.

B. Adams, B., Tack, D., and Sartori, J. (2004b) Evaluation of Digital Maps and Radio Communications in Dismounted Infantry Sections. Draft Report submitted to Defence Research and Development Canada—Toronto.

C. Adams, B., Tack, D., and Thomson, M. (2004c) Field Evaluation of Radio Communication Network Configurations in Dismounted Infantry Sections. Draft Report submitted to Defence Research and Development Canada—Toronto.

D. Adams, B., Tack, D., and Thomson, M. (2004d) Field Evaluation of Digital Maps and Radio Communication in Dismounted Infantry Sections. Draft Report submitted to Defence Research and Development Canada—Toronto.

ANNEX A:
Questionnaires

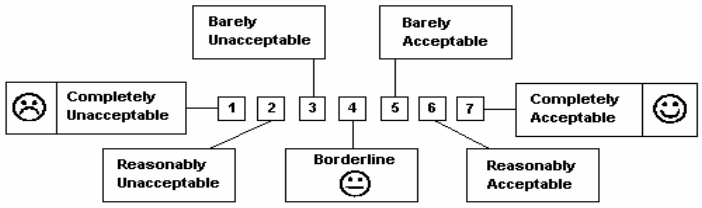
TASK QUESTIONNAIRE

PARTICIPANT NUMBER : _____ SESSION NUMBER : _____

CONDITION: **Breeze (Boom Mic)** ○ **K-99 Stinger (Throat Mic)** ○

Invisio (In-Ear) ○ **RGH-17 (Cranial Mic)** ○

USING THE SCALE PROVIDED, INDICATE THE ACCEPTABILITY OF THE FOLLOWING POINTS



1. Mission

INFORMATION TRANSFER	☹ 1	2	3	😐 4	5	6	☺ 7
Timeliness for initiating comms	○	○	○	○	○	○	○
Ease of information transfer	○	○	○	○	○	○	○
Overall Ability to Transfer Information	○	○	○	○	○	○	○
MISSION COORDINATION							
Coordination of movement	○	○	○	○	○	○	○
Coordination of fire	○	○	○	○	○	○	○
Coordination of action	○	○	○	○	○	○	○
Sharing information	○	○	○	○	○	○	○
Ability to maintain mission tempo	○	○	○	○	○	○	○
Ability to meet mission timings	○	○	○	○	○	○	○
Overall Effectiveness of Mission	○	○	○	○	○	○	○

2. COMMS SYSTEM

FIT AND COMFORT	☹ 1	2	3	😐 4	5	6	☺ 7
Fit of Speaker	○	○	○	○	○	○	○
Comfort of Speaker	○	○	○	○	○	○	○
Fit of Headset	○	○	○	○	○	○	○

FIT AND COMFORT (CONT.)	☹ 1	2	3	😐 4	5	6	☺ 7
Comfort of Headset	○	○	○	○	○	○	○
Ability to Adjust Headset	○	○	○	○	○	○	○
Fit of Microphone	○	○	○	○	○	○	○
Comfort of Microphone	○	○	○	○	○	○	○
Ability to Adjust Microphone Position	○	○	○	○	○	○	○
Restriction of Movement	○	○	○	○	○	○	○
Weight	○	○	○	○	○	○	○
Cabling	○	○	○	○	○	○	○
Size	○	○	○	○	○	○	○
Overall Fit and Comfort	○	○	○	○	○	○	○
SITUATION AWARENESS							
Ability to Hear Voices in the Surrounding Environment	○	○	○	○	○	○	○
Ability to Hear Other sounds in the surrounding Environment	○	○	○	○	○	○	○
Ability to Speak Locally (not through system)	○	○	○	○	○	○	○
Overall Ability to Maintain Situation Awareness of Sounds	○	○	○	○	○	○	○
COMPATIBILITY							
Compatibility with Clothing	○	○	○	○	○	○	○
Compatibility with Equipment	○	○	○	○	○	○	○
Compatibility with Helmet	○	○	○	○	○	○	○
Overall Compatibility	○	○	○	○	○	○	○
FUNCTION							
Clarity of Speaker Sound	○	○	○	○	○	○	○
Sensitivity of Microphone	○	○	○	○	○	○	○
Ease of Microphone Use	○	○	○	○	○	○	○
Ease of Operation of Push-to-Talk	○	○	○	○	○	○	○
Tactical Feasibility	○	○	○	○	○	○	○
Overall Function of System	○	○	○	○	○	○	○

TASK QUESTIONNAIRE

DURABILITY	☹ 1	2	3	😐 4	5	6	☺ 7
Durability of Headset	○	○	○	○	○	○	○
Durability of Microphone	○	○	○	○	○	○	○
Overall Durability	○	○	○	○	○	○	○
RELIABILITY							
Reliability of Push-to-Talk	○	○	○	○	○	○	○
Reliability of Microphone	○	○	○	○	○	○	○
Reliability of Speaker	○	○	○	○	○	○	○
Overall Reliability of Entire System	○	○	○	○	○	○	○
OVERALL SYSTEM RATING	○	○	○	○	○	○	○

Likes Dislikes

Indicate the features you liked the most about the microphone/headset combination.	Indicate the features you liked the least about the microphone/headset combination.

Improvements

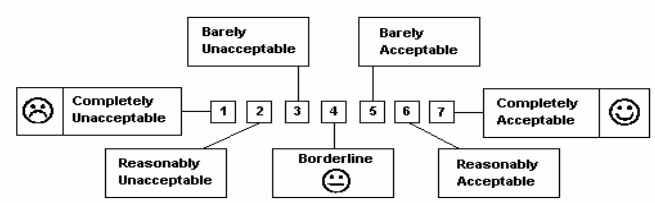
How would you improve the equipment?

TASK QUESTIONNAIRE

General Comments

EXIT QUESTIONNAIRE

PARTICIPANT NUMBER : _____ **Date: _____**



	Breeze Headset	Invisio In-Ear	K-99 Stinger (Throat mic)	RGH-17 Cranial Headgear
				
FIT AND COMFORT	☹ 1 2 3 ☐ 4 5 6 ☺ 7	☹ 1 2 3 ☐ 4 5 6 ☺ 7	☹ 1 2 3 ☐ 4 5 6 ☺ 7	☹ 1 2 3 ☐ 4 5 6 ☺ 7
Fit of Speaker	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Comfort of Speaker	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Fit of Headset	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Comfort of Headset	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ability to Adjust Headset	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Fit of Microphone	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Comfort of Microphone	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ability to Adjust Microphone Position	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Restriction of Movement	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Weight	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Cabling	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Size	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Fit and Comfort	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

	 Breeze Headset	 Invisio In-Ear	 K-99 Stinger (Throat mic)	 RGH-17 Cranial Headgear
SITUATION AWARENESS	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7
Ability to Hear Voices in the Surrounding Environment	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ability to Hear Other sounds in the surrounding Environment	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ability to Speak Locally (not through system)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Ability to Maintain Situation Awareness of Sounds	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
COMPATIBILITY				
Compatibility with Clothing	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility with Equipment	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility with Helmet	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Compatibility	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
FUNCTION				
Clarity of Speaker Sound	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Sensitivity of Microphone	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

	 Breeze Headset	 Invisio In-Ear	 K-99 Stinger (Throat mic)	 RGH-17 Cranial Headgear
FUNCTION (CONT.)	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7	☹ 1 2 3 ☺ 4 5 6 7
Ease of Microphone Use	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of Operation of Push-to-Talk	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Tactical Feasibility	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Function of System	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
DURABILITY				
Durability of Headset	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Durability of Microphone	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Durability	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
RELIABILITY				
Reliability of Push-to-Talk	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Reliability of Microphone	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Reliability of Speaker	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Reliability of Entire System	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
OVERALL SYSTEM RATING	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

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12QG01

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(U) This report describes a three−day experiment investigating input and display devices for voice communications in the context of urban section attacks. Four input/display pairs were investigated: 1) a boom microphone input device combined with an open ear speaker display, 2) an in−ear bone−conduction input device and an in−ear bone−conduction speaker display, 3) a throat microphone input device combined with a helmet−mounted speaker display and 4) a cranial bone−conduction input device with a cheek bone−conduction speaker display. The aims of the experiment were to compare the effectiveness of different input and display devices for radio communication and to identify the optimum input/display combination for intra−section infantry radios. Sixteen soldiers organized into two sections were participants in the experiment. The participants completed a series of section attacks against three enemy force soldiers in an urban environment, while communicating using each of the four systems under investigation. Each participant used each configuration twice for a total of eight section attacks per participant. Data collection included questionnaires, focus groups and HF observer assessments. Questionnaire data was collected in nine categories: Information Transfer, Mission Coordination, Fit and Comfort, Situation Awareness, Compatibility, Function, Durability, Reliability and Overall Evaluation. The data collected from the questionnaires indicated a preference for the cranial bone−conduction input device with a cheek bone−conduction speaker display, provided some design changes were incorporated to make it more compatible with the Canadian Infantry Helmet. The in−ear bone−conduction input device and speaker display and the boom microphone input device combined with an open ear speaker display were second and third choices respectively. The throat microphone input device combined with a helmet−mounted speaker display was the last choice system, and was rated unacceptable overall by more than 20% of participants for Fit and Comfort, Compatibility, Function, Durability, Reliability and Overall Evaluation.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Soldier Information Requirements Technology Demonstration Project; SIREQ TD; radio communications; communications; display devices; bone−conduction; throat microphone; helmet−moounted speaker; infantry section communication; information exchange