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EVALUATION OF VISUAL, AUDITORY AND TACTILE DISPLAYS OF GPS-BASED LOCALIZATION INFORMATION FOR SOLDIERS ON THE BATTLEFIELD

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Abstract

This report describes an investigation of various displays of GPS-based position, bearing and distance information using three systems: 1) an augmented reality visual display in a head-mounted virtual retinal device; 2) a 3D audio system using tone pitch and frequency cues; and 3) an eight-tactor chest-distributed tactile system. These systems were compared to a map and compass baseline condition for localizing both stationary and moving battlefield entities within the context of platoon attack missions. Performance measures included distance and bearing estimation accuracy, and time required for distance and bearing estimations. Acceptability data were collected in the form of workload questionnaires, exit questionnaires, focus groups and human factors observer assessments.

Overall, GPS- based navigation information systems were found to provide advantages over a map-and-compass-based system. Of the three systems tested, the visual display was preferred; however, it tended to compromise the soldier's situation awareness. Performance trends also indicated that the bearing and distance estimations and time required to use the system were best with the visual display system. If a soldier is in a situation where his visual sense is already overloaded, localization information displayed using a tactile method may be preferable. Improvements to an audio method including non-occluding ear cups and customisable 3D sound could make the audio method of information localization viable.

Résumé

Le présent rapport décrit une étude portant sur divers affichages d'information GPS de position, relèvement et distance faisant appel à trois systèmes : 1) un affichage visuel de réalité augmentée dans un dispositif rétinien virtuel monté sur casque; 2) un système audio 3D faisant appel à des repères de hauteur tonale et de fréquence; 3) un système tactile à huit transducteurs tactiles porté sur la poitrine. On a effectué une comparaison de l'utilisation de ces systèmes avec l'utilisation d'un système carte-boussole de base pour localiser des entités de champ de bataille tant fixes que mobiles dans le contexte de missions offensives de pelotons. Les mesures des performances avaient trait à la précision de l'estimation de distance et de relèvement, ainsi qu'au temps requis pour les estimations de distance et de relèvement. Des données d'acceptabilité ont été recueillies au moyen de questionnaires portant sur la charge de travail, de questionnaires finaux, de groupes de consultation et d'évaluations par des observateurs des facteurs humains.

Globalement, les systèmes d'information de navigation GPS offraient des avantages par rapport au système basé sur l'utilisation d'une carte et d'une boussole. Des trois systèmes sur lesquels a porté l'essai, le système à affichage visuel était le préféré; cependant, il avait tendance à compromettre la connaissance de la situation par le soldat. Les tendances des performances ont aussi montré que les estimations de relèvement et de distance ainsi que le temps requis pour utiliser le système étaient les meilleurs avec le système à affichage visuel. Lorsqu'un soldat se trouve dans une situation qui sollicite déjà excessivement son sens de la vision, la présentation de l'information de localisation au moyen d'une méthode tactile pourrait être préférable. Des améliorations d'une méthode audio, entre autres l'ajout de cache-oreilles antibruit non obstruants et l'utilisation de son 3D personnalisable, pourraient rendre viable la méthode audio de localisation de l'information.

Executive Summary

This report describes an evaluation of three ways of displaying position, direction and distance information to soldiers in the field. GPS-based information was displayed by: 1) an augmented reality visual display in a head-mounted virtual retinal device; 2) a 3D audio system using tone pitch and frequency cues; and 3) an eight-tactor chest-distributed tactile system. These systems were compared to a map and compass baseline condition for localizing both stationary and moving battlefield entities within the context of platoon attack missions.

Further aims of this study were:

- To investigate the differences in situation awareness and mental workload between localization modalities.
- To assess the tactical feasibility and usability issues specific to the different modalities.

The field trial took place in Ft. Benning, Georgia with eight soldier participants. This experiment was run in conjunction with platoon attacks that were conducted for other studies in the SIREQ-TD experimentation series. Soldiers participating in the information localization study did not participate as members of the assaulting or defending force during the platoon attacks. Instead, they navigated preset routes using a map and compass, moving independently from the attacking sections. Participants were stopped at measurement points along the routes and asked to use the localization tools to determine the distance and bearing to both moving and static friendly and enemy locations. They made distance and bearing estimations using each of four conditions: augmented reality visual, 3D audio, chest-distributed tactile, and map and compass (baseline). Other measures included subjective questionnaires on workload, usability and tactical feasibility. Data collection also included focus groups and observer assessments. A complete-block, repeated-measures analysis of variance was undertaken for all performance data and a Friedman ANOVA was used for questionnaire data. Differences were identified at $p \leq 0.05$.

Map and Compass Baseline

Participants found the map and compass baseline condition to be acceptable for an information localization task. However, they indicated on the exit questionnaire that the visual system was preferred over the map and compass. This condition was consistently rated most acceptable for items relating to physical comfort, usability and compatibility. In terms of performance, distance estimations to moving locations were worse with the map and compass than with all other systems. Trends indicate that bearing estimations were also less accurate with this baseline system, but this difference was only significant as compared to the visual condition. There was also much more variability in performance with this system than with the GPS-based systems. The time required to determine the distance and bearing measurements was significantly higher with the map and compass than with the other systems.

Audio

The audio system was consistently rated the least acceptable on the exit questionnaire. Participants had concerns relating to ease of terrain traverse, physical comfort, situation awareness, usability and tactical feasibility. Further research using participant-specific HRTFs and voice displays instead of tones of varying rate and pitch is recommended.

Tactile

The tactile system was generally considered acceptable by participants, although not as accurate as the visual system. The tactile system had the advantage of not obstructing the participant's field of view or interfering with his ability to traverse terrain. A rugged tactor system, designed for military use, could eliminate concerns regarding compatibility and durability.

Visual

Overall results indicate that the visual system was the preferred system for the information localization task. Performance results indicate that bearing estimations were best with the visual system. Although the differences were not significant at the $p<0.05$ level, trends also indicate that distance estimations and time required to use the system were also best with the visual display system. The physical display did compromise visual situation awareness and hampered detection of ground level hazards while traversing terrain. Participants indicated that they would prefer a display that could be moved out of their field of view when not in use, and easily transferred from the left to the right eye. The system was also washed out by bright sunlight-- a daylight readable display is necessary.

Overall

Overall, GPS- based localization systems provided advantages over a map-and-compass-based system. Of the three displays tested, the augmented reality visual display was preferred; however, a soldier's situation awareness was still somewhat compromised. If a soldier is in a situation where his visual sense is already overloaded, localization information displayed using a tactile method may be preferable. Improvements to an audio method, including non-occluding ear cups and customisable 3D sound, could make the audio method of information localization more viable.

Sommaire

Le présent rapport décrit une évaluation de trois méthodes d'affichage d'information de position, direction et distance à l'intention des soldats en campagne. L'information GPS a été affichée au moyen des systèmes suivants : 1) un affichage visuel de réalité augmentée dans un dispositif rétinien virtuel monté sur casque; 2) un système audio 3D faisant appel à des repères de hauteur tonale et de fréquence; 3) un système tactile à huit transducteurs tactiles porté sur la poitrine. On a effectué une comparaison de l'utilisation de ces systèmes avec l'utilisation d'un système carte-boussole de base pour localiser des entités de champ de bataille tant fixes que mobiles dans le contexte de missions offensives de pelotons.

L'étude visait aussi les objectifs suivants :

- Examiner les différences de connaissance de la situation et de charge de travail mental entre les modalités de localisation.
- Évaluer les questions de faisabilité tactique et de convivialité propres aux différentes modalités.

L'essai sur le terrain a été réalisé à Fort Benning (Géorgie), avec huit soldats participants. L'expérience a été menée conjointement avec des attaques de peloton effectuées aux fins d'autres études dans le cadre de la série d'expériences du Projet de démonstration technologique des besoins des soldats en matière d'information (SIREQ TD). Les soldats participant à l'étude de localisation d'information n'ont pas participé en tant que membres de la force d'attaque ou de défense durant les attaques du peloton. Ils ont plutôt parcouru des trajets pré-établis en se servant d'une carte et d'une boussole, se déplaçant indépendamment des sections d'attaque. Les participants étaient arrêtés à des points de mesure sur les trajets et on leur demandait d'utiliser les outils de localisation pour déterminer la distance et le relèvement par rapport à des positions amis et ennemis, tant mobiles que fixes. Ils ont fait des estimations de distance et de relèvement pour chacune des quatre conditions suivantes : système visuel de réalité augmentée, système audio 3D, système tactile porté sur la poitrine et système carte-boussole (système de base). Les autres mesures étaient faites au moyen de questionnaires subjectifs portant sur la charge de travail, la convivialité et la faisabilité tactique. Des données ont également été recueillies à partir de discussions en groupes de consultation et d'évaluations faites par des observateurs. Une analyse de variance de mesures répétées, de bloc complet, a été effectuée pour toutes les données de performance et une analyse de variance de Friedman a été utilisée pour les données de questionnaire. Des différences ont été identifiées à $p \leq 0,05$.

Système carte-boussole de base

Les participants ont trouvé que l'utilisation du système carte-boussole de base était acceptable pour l'exécution de la tâche de localisation d'information. Cependant, ils ont indiqué sur le questionnaire final que le système visuel était préférable au système carte-boussole. Ce système était coté de façon constante comme très acceptable des points de vue du confort physique, de la convivialité et de la compatibilité. Du point de vue des performances, les estimations de distance par rapport à des positions mobiles obtenues avec le système carte-boussole étaient moins bonnes que les estimations obtenues avec tous les autres systèmes. Les tendances montrent que les

estimations de relèvement obtenues avec ce système de base étaient également moins précises, mais la différence était importante seulement par comparaison avec les estimations obtenues avec le système visuel. La variabilité de performance était aussi beaucoup plus grande avec ce système qu'avec les systèmes GPS. Le temps requis pour déterminer la distance et le relèvement était beaucoup plus grand avec le système carte-boussole qu'avec les autres systèmes.

Système audio

Le système audio a été constamment coté comme le moins acceptable sur le questionnaire final. Les participants avaient certaines craintes quant à la facilité de traversée de terrain, au confort physique, à la connaissance de la situation, à la convivialité et à la faisabilité tactique. On recommande d'effectuer d'autres travaux dans lesquels on utilisera des affichages vocaux et des fonctions de transfert reliées à la tête (HRTF) propres aux participants plutôt que des tonalités de débit et de hauteur variables.

Système tactile

Le système tactile était généralement considéré comme acceptable par les participants, même si on ne le trouvait pas aussi précis que le système visuel. Le système tactile avait l'avantage de ne pas obstruer le champ de vision des participants et de ne pas le gêner pour la traversée de terrain. Un système robuste à transducteurs tactiles, conçu pour utilisation militaire, pourrait éliminer les craintes concernant la compatibilité et la durabilité.

Système visuel

Globalement, les résultats montrent que le système visuel était le système préféré pour la tâche de localisation d'information. Les mesures des performances indiquent que les meilleures estimations de relèvement ont été obtenues avec le système visuel. Même si les différences n'étaient pas importantes au niveau $p < 0{,}05$, les tendances montrent aussi que les meilleures estimations de distance et le meilleur temps requis pour utiliser le système ont aussi été obtenus avec le système d'affichage visuel. L'affichage physique a réellement compromis la connaissance de la situation visuelle et a restreint la détection des dangers au niveau du sol durant la traversée de terrain. Les participants ont indiqué qu'ils préféreraient un affichage pouvant être retiré de leur champ de vision lorsqu'il n'est pas utilisé et pouvant être transféré facilement de l'œil gauche à l'œil droit. L'affichage disparaissait complètement en condition de plein soleil – un affichage lisible à la lumière du jour est nécessaire.

Résultats globaux

Globalement, les systèmes de localisation GPS offraient des avantages par rapport au système carte-boussole. Des trois systèmes sur lesquels a porté l'essai, le système d'affichage visuel de réalité augmentée était le préféré; cependant, la connaissance de la situation par le soldat était encore quelque peu compromise. Lorsqu'un soldat se trouve dans une situation qui sollicite déjà excessivement son sens de la vision, la présentation de l'information de localisation au moyen d'une méthode tactile pourrait être préférable. Des améliorations d'une méthode audio, entre autres l'ajout de cache-oreilles antibruit non obstruants et l'utilisation de son 3D personnalisable, pourraient rendre viable la méthode audio de localisation de l'information.

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List of Acronyms

The following acronyms are used in this report:

ANOVA:	Analysis of Variance
DGPS:	Differential Global Positioning System
FFOV:	Forward Field of View
FIND:	Future Infantry Navigation Device
GPS:	Global Positioning System
HMD:	Head (or Helmet) Mounted Display
HRTF:	Head-Related Transfer Function
NVG:	Night Vision Goggle
SIREQ-TD:	Solider Information Requirements-Technology Demonstration
VRD:	Virtual Retinal Display

1. Background

The SIREQ-TD (Soldier Information Requirements- Technology Demonstration) project has investigated the information needs of infantry soldiers in a variety of mission situations. The SIREQ cognitive task analyses identified a need for more information for infantry soldiers. However, information must be distributed to soldiers in a manner that is not disruptive to other soldiering tasks.

A study conducted by Glumm et al (1998) indicated some advantages to helmet-mounted visual displays. The objective of the Glumm et al study was to measure soldier performance during land navigation and other mission tasks using in-service navigational equipment and to compare these data with performance using navigational information integrated on a Helmet Mounted Display (HMD). The in-service navigational equipment consisted of a paper map, protractor, lensatic compass and a hand-held GPS. The HMD condition contained two displays of integrated information, a map of the area and a rolling compass. A significant difference was observed in navigational accuracy when using actual distance travelled where the HMD condition travelled less distance, and required less mental workload to employ.

A second study by Glumm et al (1999) measured soldier performance during land navigation and target acquisition tasks when position information was provided visually on an HMD versus providing the same information in verbal audio messages. The results indicated that differences between the visual and auditory displays were not statistically significant for navigation, target acquisition, workload, and cognitive performance. These studies indicated that helmet-mounted visual displays and auditory displays might be appropriate ways to display information to soldiers.

A series of studies which compared the display of navigation information in visual, auditory or tactile format have been conducted as part of the SIREQ-TD program (Kumagai et al 2001a, 2001b, 2002a). These studies indicated certain advantages for all three display modalities. The visual display was found easy to use, but the occluded display obstructed the visual field. The audio modality was found effective because it did not impede the visual field. The tactile display had advantages in that it could be used while moving and freed the other senses for visually searching for targets or listening for communications or enemy movement.

A study focusing on the use of tactile systems (Kumagai et al 2002b) compared various placements for tactors on the soldiers' body. The study compared torso, chest, wrist and neck configurations for tactor placement. Results indicated that an eight-tactor chest or torso configuration improved performance and was preferred by soldiers.

Another study was conducted focussing on audio displays (Kumagai et al 2002c). This study investigated mono (1 dimensional), stereo (2 dimensional) and 3 dimensional displays for audio tones indicating the location of a point of interest. Varying tone pitch and frequency was also investigated. Results indicated that 2D and 3D auditory displays performed better than 1D displays with changing rate and pitch. The participants preferred to have additional cues of angular distance to the bearing (changing rate and/or pitch). The 3D auditory displays were enhanced by the inclusion of additional cues.

Another SIREQ-TD study (Woods et. al. 2004) compared head-mounted, heads-up virtual retinal and weapon-mounted visual displays during a wayfinding and target detection task. While questionnaire and focus group results indicated the participants' preference for the weapon-mounted display over the two head-mounted displays, performance results indicated no significant difference between the three displays in target engagement performance. Additionally there were only small differences in wayfinding performance between the three displays. Of the two head-mounted displays, the virtual retinal display was preferred by the participants.

A further SIREQ-TD study has investigated the feasibility of using visual augmented reality systems during way-finding tasks (Woods et. al. 2004). In this work, soldiers used a visual augmented reality system to determine the distance and bearing to various pre-programmed locations (enemy locations or friendly rendezvous points). Results indicated that distance and bearing estimations using the augmented reality system were more accurate than estimations made using the baseline map and compass condition. However, this research investigated only stationary targets. More realistic battlefield situations with moving target locations needed to be investigated. Also, while the study mentioned investigated visual representations of augmented reality information, tactile and auditory modalities had not been investigated for their usefulness for information localization in a battlefield environment.

The study described in this report investigates three GPS-based information display systems: 1) an augmented reality visual display in a head-mounted virtual retinal device; 2) a 3D audio system using tone pitch and frequency cues; and 3) an eight-tactor chest-distributed tactile system. These systems were compared to a map and compass baseline condition for localizing both stationary and moving battlefield entities within the context of platoon attack missions.

2. Aims

The aims of this study were to:

- Investigate the effects of using augmented reality visual, 3D audio and chest-distributed tactile display modalities for information display on the battlefield, as compared to a map and compass baseline condition.
- Evaluate the effectiveness of localization systems when both the user and the target are moving.
- Investigate the differences in situation awareness and mental workload between display modalities.
- Assess the tactical feasibility and usability issues specific to the different display modalities.

3. Method

This section provides an overview of the field trial method followed by an explanation of detailed procedures, equipment, experimental conditions and measures.

3.1 Overview

The following description provides a general overview of the trial method.

The field trial took place in Fort Benning, Georgia during the period 8 – 16 November 2003 with eight soldier participants from the 3rd Battalion of the Princess Patricia Canadian Light Infantry (3PPCLI) from Edmonton, Alberta. This experiment was run in conjunction with platoon attacks that were conducted for other studies in the SIREQ-TD experimentation series. Eight platoon attack missions were conducted with an assaulting force--comprising a Company HQ, a Platoon HQ, three dismounted infantry Sections, and a weapons detachment--to assault one defending Section. Soldiers participating in the information localization study did not participate as members of the assaulting force or defending section during the platoon attacks. Instead, they navigated preset routes using a map and compass, moving independently and out of visual range from the attacking sections. Participating soldiers were stopped at a measurement point along the route and asked to use one of the localization tools to determine the distance and bearing to both moving and static friendly and enemy locations. They made distance and bearing estimations using each of four conditions: augmented reality visual, 3D audio, chest-distributed tactile and map and compass (baseline). Other measures included subjective questionnaires on workload, usability and tactical feasibility. Data collection also included focus groups and observer assessments.

3.2 Detailed Procedures

Participants were briefed on all pertinent aspects of the trial protocol and schedule, and were trained in the use of the information localization displays prior to the start of the trial.

The Platoon missions began with each of the three Sections being deployed to an initiation point approximately 2500 metres from their respective objectives. At the same time, soldiers participating in this information localization study began navigating independent routes from separate initiation points, using a map and compass for navigation. A Human Factors (HF) observer accompanied each soldier. Planned section routes and known static enemy locations were shown on the map provided to the soldier. See Figure 1.

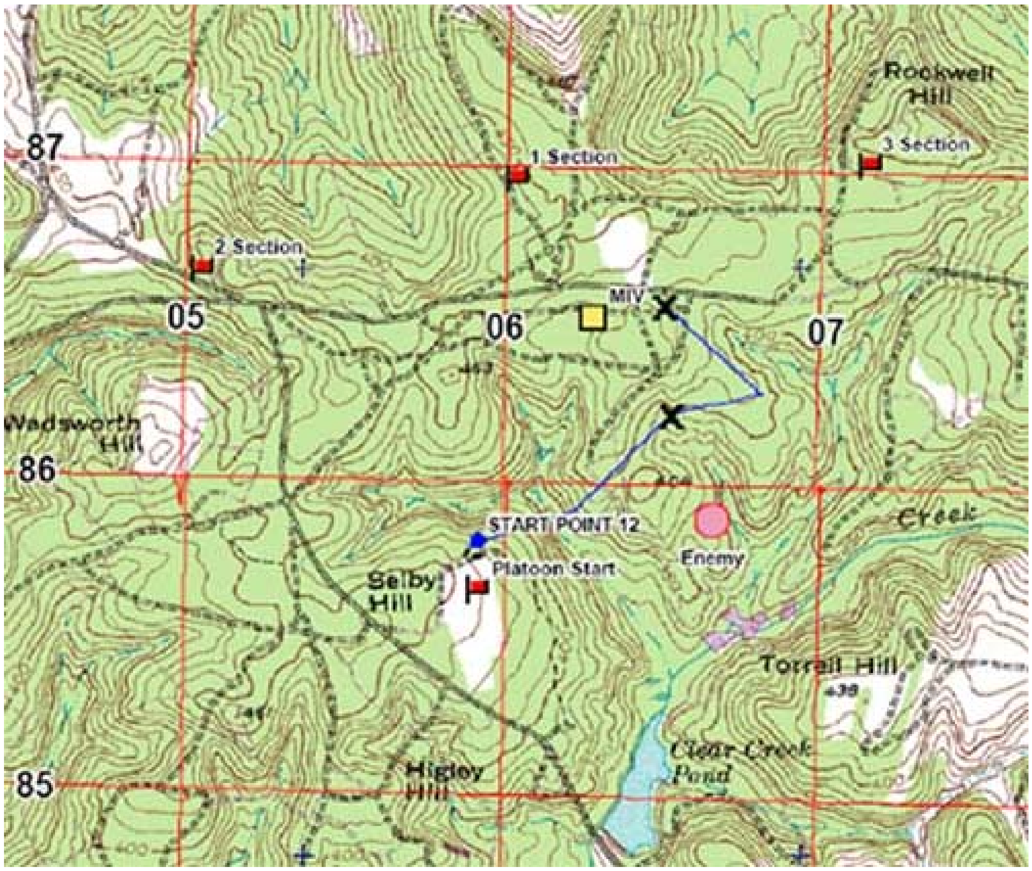


Figure 1: Sample Mission Map Provided to the Participant

Each soldier used each of the 4 experimental conditions in a balanced order presentation: augmented reality visual, 3D audio, chest-distributed tactile and map and compass (baseline). During each platoon attack, soldiers used either one or two information display modalities. On days when soldiers used two modalities, they were stopped once at a predetermined measurement point before their route midpoint by the HF observer and asked to use the first modality to determine the distance and bearing to 2 moving friendly locations (other sections) and 2 static locations. After the route midpoint, they were stopped at an additional measurement point on the route and asked to determine the distance and bearing to 2 moving friendly locations (other sections) and 2 static enemy targets, using the second information display modality. On days when soldiers used only one modality, they were stopped only once before the route midpoint and asked to make distance and bearing estimations as above using their assigned modality. The participant indicated his distance estimation by verbally giving the distance in metres. He indicated his bearing estimation by pointing to the location while holding a Garmin E-trex Summit GPS in digital compass mode. The HF observer then read the bearing from Garmin E-trex summit and recorded it in mils. The HF observer also recorded the time required for each measurement point. At the measurement point, the HF observer contacted staff embedded with the assaulting sections by radio for the purpose of obtaining a grid reference for that section for use in determining the distance and bearing to that section in the map and compass condition.

3.3 Equipment

This section explains the equipment used during the field trial.

3.3.1 The FIND System

Three GPS-based information localization modalities were investigated in this experiment: augmented reality visual, 3D audio and chest-distributed tactile. A map and compass condition was used as a baseline condition.

In each GPS-based condition, the information localization displays were generated using the Future Infantry Navigation Device (FIND) system. FIND was developed by Humansystems Incorporated in conjunction with Oerlikon Aerospace to generate wayfinding displays and capture wayfinding performance data. It was modified for use as an information localization system for this experiment.

The FIND system consisted of a small laptop computer, a global positioning system (GPS) receiver, a Digital GPS (DGPS) beacon receiver, an electronic compass, and the associated power supplies (Figures 2 & 3). Position coordinates of static locations of interest were pre-programmed into the computer. For moving locations of interest, the position coordinates were updated throughout the mission using a two-way digital GPS receiver. During a mission, the soldier's location and orientation, as measured by the GPS and the electronic compass, were updated once every second. The bearing of the soldier's head, measured by the electronic compass mounted to the helmet, was updated 10 times every second.

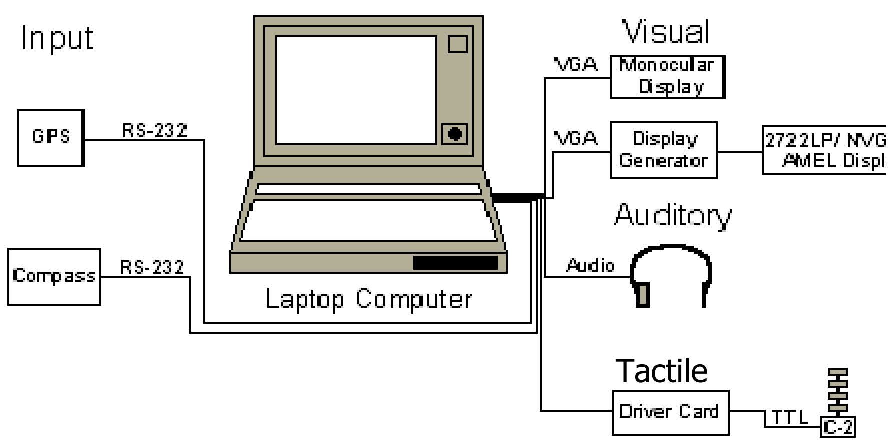


Figure 2: FIND System Schematic

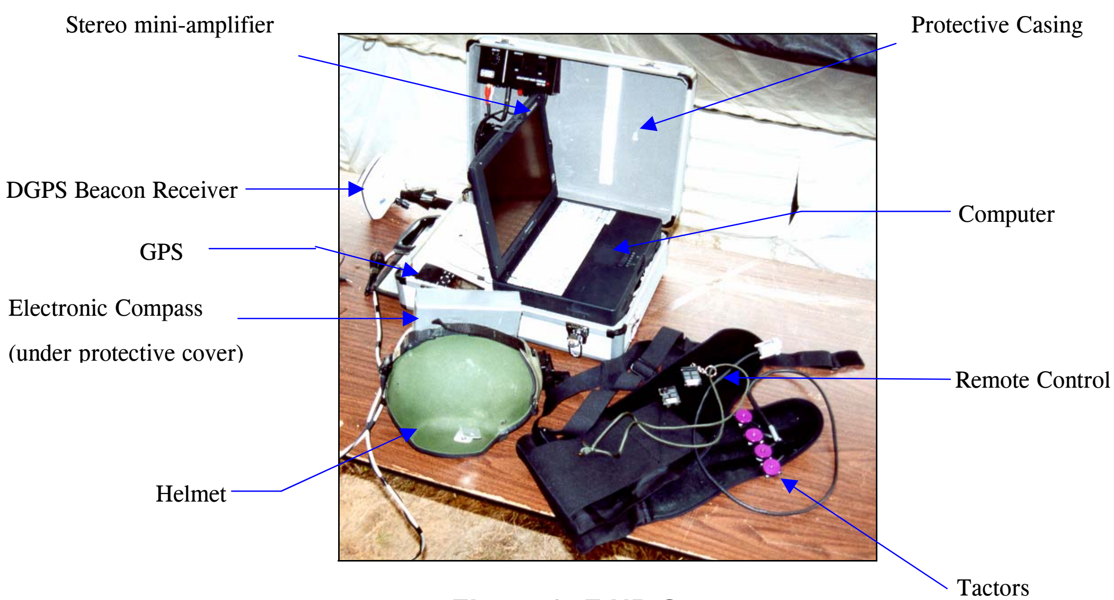


Figure 3: FIND System

The FIND system worked by relating the user's own location (GPS) and facing direction (electronic compass on head) to the location of interest (Figure 4). The difference between the facing direction and the location bearing produced the off-set bearing for display in the visual, audio or tactile modality.

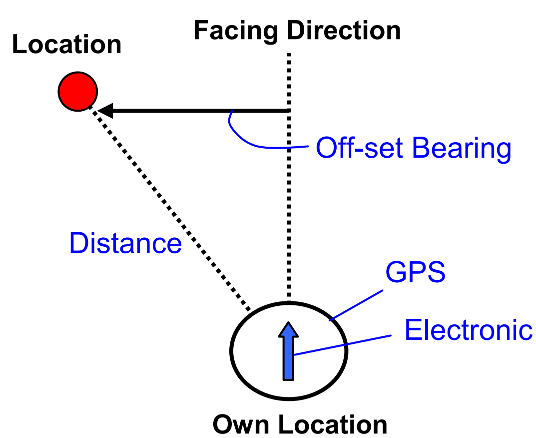


Figure 4: FIND Output Data

Although the FIND system was continuously operating during each experimentation route, the participant used its information only at the measurement points. To activate the display for each of the four locations of interest, the participant pressed each of four corresponding buttons on a hand-held remote control.

3.3.2 Experimental Conditions

This section explains the experimental conditions and the equipment used for each of them.

Map and Compass Baseline

In all conditions, participants were provided with a 1:25,000 map indicating their route and critical mission locations—see Figure 1. They were also provided with a mission route card indicating the distance and bearing of their route legs and eight figure MGRS grid references for their waypoints. They used their in-service compasses.

In the baseline condition, soldiers used the map and compass in conjunction with the grid coordinates received by radio to determine the distance and bearing to the moving friendly sections. The static locations were indicated on the mission map. In the GPS-based conditions, they used the map and compass for navigation only.

Augmented Reality Visual

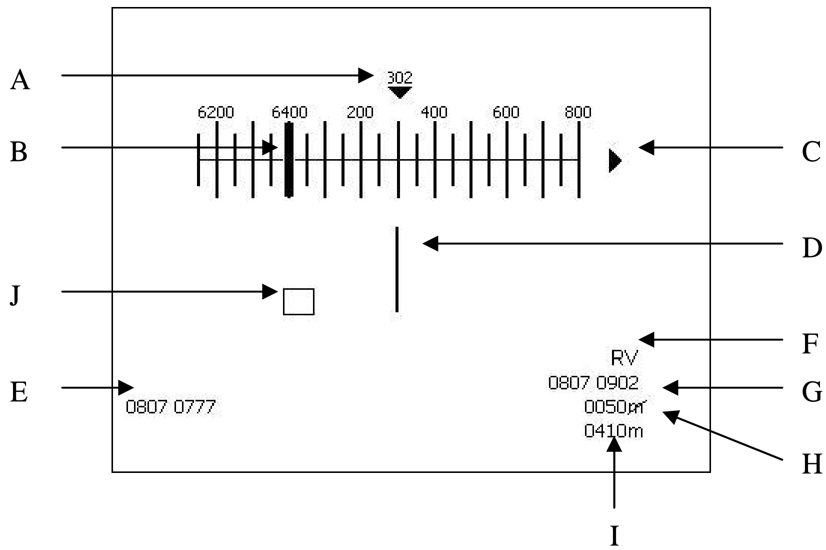
The see-through virtual retinal display (VRD), Nomad by Microvision (see Figure 5), was used to display the visual augmented reality interface for this experiment. The Nomad consisted of a display module and optical combiner in a monocular headset display. These were connected to a controller module and then to the FIND system computer.

The VRD worked by emitting a pulse beam containing an image in a pixel-by-pixel stream onto a mirror. The mirror reflected the beam toward the optical combiner. Lenses in the optical combiner diverted the beam through the pupil into the eye. The beam swept horizontally across the retina in a straight line, hitting photoreceptors one pixel at a time. When the beam reached the end of each line, it moved back to the other side and down slightly to draw the next line of the image.

Weight (head-worn display)	502 g
Video Resolution	800 x 600

Figure 5: Microvision Nomad Virtual Retinal Heads-Up Display

The information localization software display that was displayed on the NOMAD VRD is shown in Figure 6.



Features
A – Current Heading
B – Cardinal Directions (N, E, W, S)
C – Direction to Location
D – Landmark Alignment Bar
E – Current Grid
F – Label of Active Location
G– Location Grid
H– Bearing to Location
I – Distance to Location
J –Location Icon (Friendly)

Figure 6: Visual Display

Chest-Distributed Tactile Modality

The chest-distributed tactor display modality was also driven by the FIND system. The participating soldier wore an elastic belt holding eight tactile transducers in a belt around his chest (see Figure 9) When the soldier turned his head to face a location of interest, the corresponding tactor vibrated to let him know that he was facing the correct direction.

Previous SIREQ work has indicated that this eight tactor chest-distributed system was not only preferred by soldiers but also improved performance in determining waypoint locations when compared to two and three-tactor systems. (Kumagai and Hawes, 2002b).

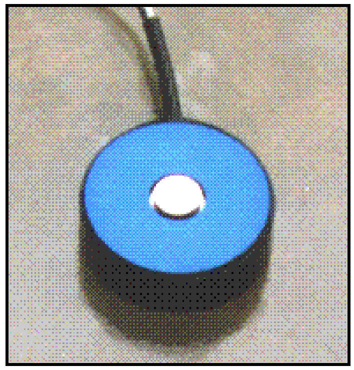


Figure 7: Model C1-97 Tactile Transducer

The Model C1-97 Tactile Transducer (Figure 7) has the following physical description:

- Housing = 32.004 mm diameter by 11.684 mm high
- Mass = 26 grams
- Electrical Wiring = #24 AWG leads
- Skin Contactor = 7.9502 mm diameter, raised 0.635 mm from housing, pre-loaded on skin

Each vibrotactile transducer was mounted to an elastic belt worn around the chest. All transducers were connected to the tactor box worn on the participant's back (Figure 8). The tactor box was linked to the FIND system.

Figure 8: Tactor Box Housing Eight Vibrotactile Transducers

The arrangement of the tactors is shown in Figures 9 and 10. The eight tactors wrapped around the participant's chest in a horizontal line below the nipple line (in line with the xyphoid process). The front-middle tactor was placed vertically in line with the belly button, over the xyphoid process, the right and left tactors were located on the right and left sides of the ribcage, respectively, and the back-middle tactor was vertically in line with the spine. The other four tactors were placed at an equal distance around the chest between the front, right, back, and left tactors.

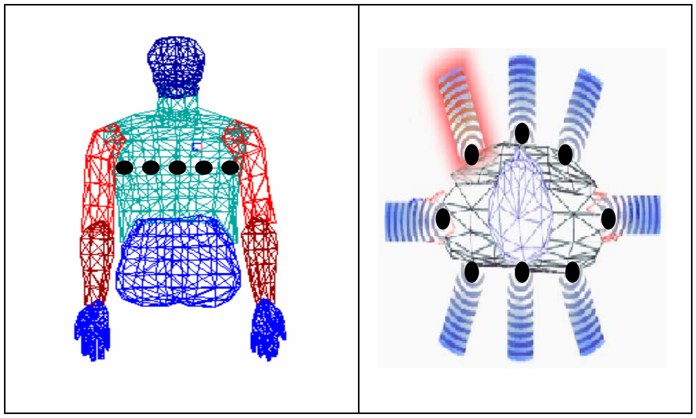


Figure 9: Chest-Distributed Design

Figure 10: Chest-Distributed Set-Up

When the participant pressed the remote control to activate the tactor display, a voice announced the name of the location and the distance to the location in metres, before the tactors were activated.

3D - Audio Modality

3D Audio sounds were generated by the FIND system and sent to Sennheiser HD 580 Headphones. The headphones were circumaural open dynamic stereo HiFi professional headphones. The frequency response was 12-38,000 Hz (-10dB) and 16-30,000 Hz at (-3 dB). See Figure 11.

Figure 11: Audio Modality Set-up

The 3D Audio system worked by generating a constant rate and pitch tone in 3D space when the soldier faced the location of interest. In order to generate a tone from the direction of the location of interest, the system used a generic head-related transfer functions (HRTF) to create a spatial 3D tone as an indicator of the direction of the waypoint, 360º around the soldier's head. The spatial position of the tone shifted in relation to bearing of the location of interest and the soldier's head in the horizontal plane as the soldier turned his head. When the soldier's head was facing the location of interest the tone spatially sounded as though it was in front of the soldier

When the participant pressed the remote control to activate the audio display, a 2D audio voice announced the name of the location and the horizontal distance to the location in metres, before the 3D tones were activated.

3.4 Measures

The following measures were taken during the experiment:

Performance Measures

- Bearing Estimation Accuracy: Participants were stopped once on their route and asked to use their information localization aid to determine the bearing from their current location to four battlefield locations (two static locations and two moving locations). The difference between the bearing given and the actual bearing was calculated.

- Distance Estimation Accuracy: Participants were stopped once on their route and asked to use their information localization aid to determine the distance from their current location to four battlefield locations (two static locations and two moving locations). The difference between the distance given and the actual distance was calculated.

- Time for Measurement Point: The HF observer recorded the time required for soldiers to provide the four distances and four bearings using each modality.

Exit Questionnaire

At the end of experimentation, participants were required to complete an exit questionnaire with regards to each of the four conditions. (Questionnaires are provided at Annex A). Questions related to:

- Effectiveness for Information Localization
- Effectiveness for Terrain Traverse
- Physical Comfort
- Usability
- Compatibility
- Overall System Evaluation

Participants used the seven-point acceptability scale in Figure 12 to respond to the questionnaire.

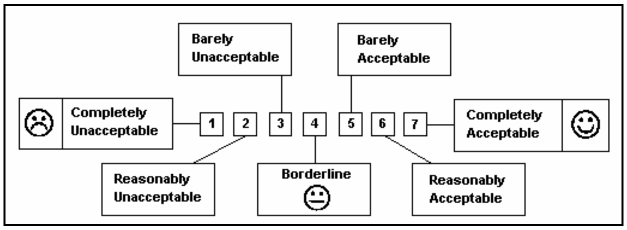


Figure 12: The Seven-Point Acceptability Scale

NASA TLX Questionnaire

At the completion of each mission, participants completed NASA TLX workload questionnaires, which asked them to rate their workload for the task on a 10-point scale in the following six categories:

- Mental Demand (thinking, deciding, searching, remembering)
- Physical Demand (controlling, operating, activating)
- Temporal Demand (time pressure)
- Performance (how successful and how satisfied were you with performing this task?)
- Effort (how hard did you have to work, both mentally and physically?)
- Frustration

Focus Group

Focus group discussions were also held at the completion of the experiment to compare and contrast information display capabilities.

4. Statistical Analyses

A complete-block, repeated-measures analysis of variance was undertaken for all performance data and a Friedman ANOVA was used for questionnaire data. The statistical plan in shown in Table 1. Differences were identified at $p \leq 0.05$.

Table 1: Statistical Plan

Item	Sample Size	Tests Performed
Performance Data	8	ANOVA
Workload Questionnaire	8	ANOVA
Exit Questionnaire	8	Non-parametric Friedman's ANOVA

5. Results

This section presents results including participant information, performance results, exit and workload questionnaire results and focus group results.

5.1 Participants

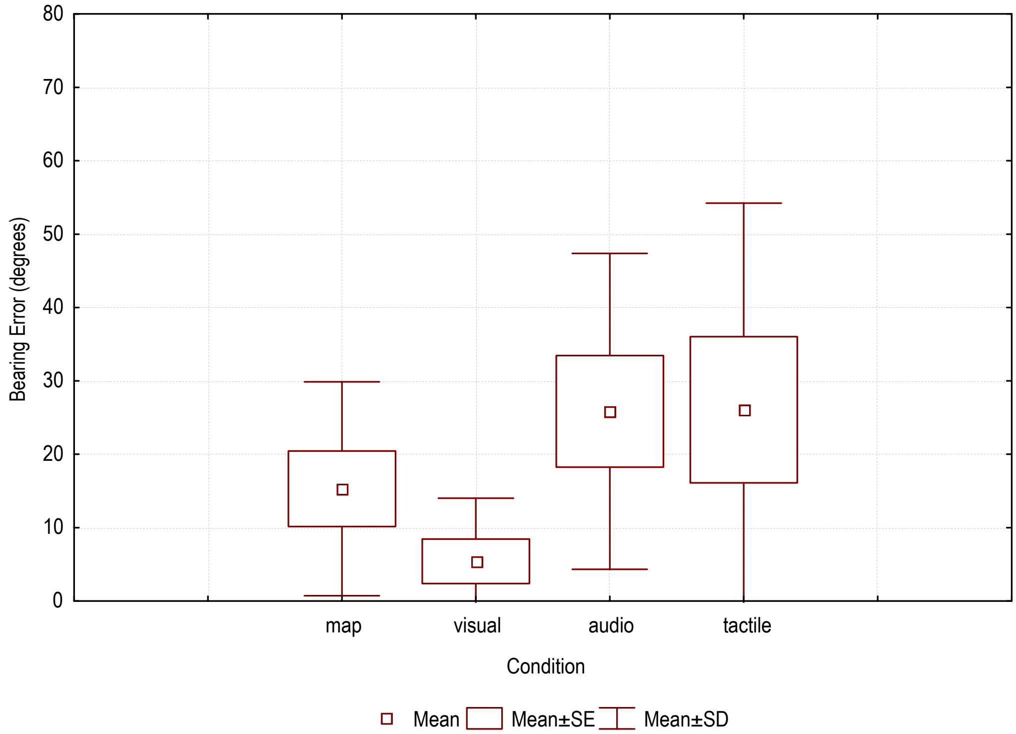
Four Sergeants, three Master Corporals and one Corporal from the 3rd Battalion of the Princess Patricia Canadian Light Infantry (3PPCLI) from Edmonton, Alberta participated in this experiment. Their average age was 31.25 years and their average length of regular force service was 95.5 months (almost eight years).

5.2 Performance Results

The following sections present the mission performance results including distance and bearing estimation error results and the time required for measurement points.

5.2.1 Bearing Estimations to Static Locations

At the measurement point, participants used their information localization aid (map and compass, visual, audio or tactile) to determine the bearing from their current location to two known locations on the battlefield (RV and Enemy). These locations were static and marked on the mission map. The difference between the bearing provided and the actual bearing was calculated and averaged for the two locations. Since the data was not normally distributed, a log transformation was performed on the data, and a repeated-measures ANOVA was conducted on the transformed data with the information localization aid as the within-subjects effect. The results of this analysis and the means and standard deviations (for the untransformed data) are presented in Figure 13.



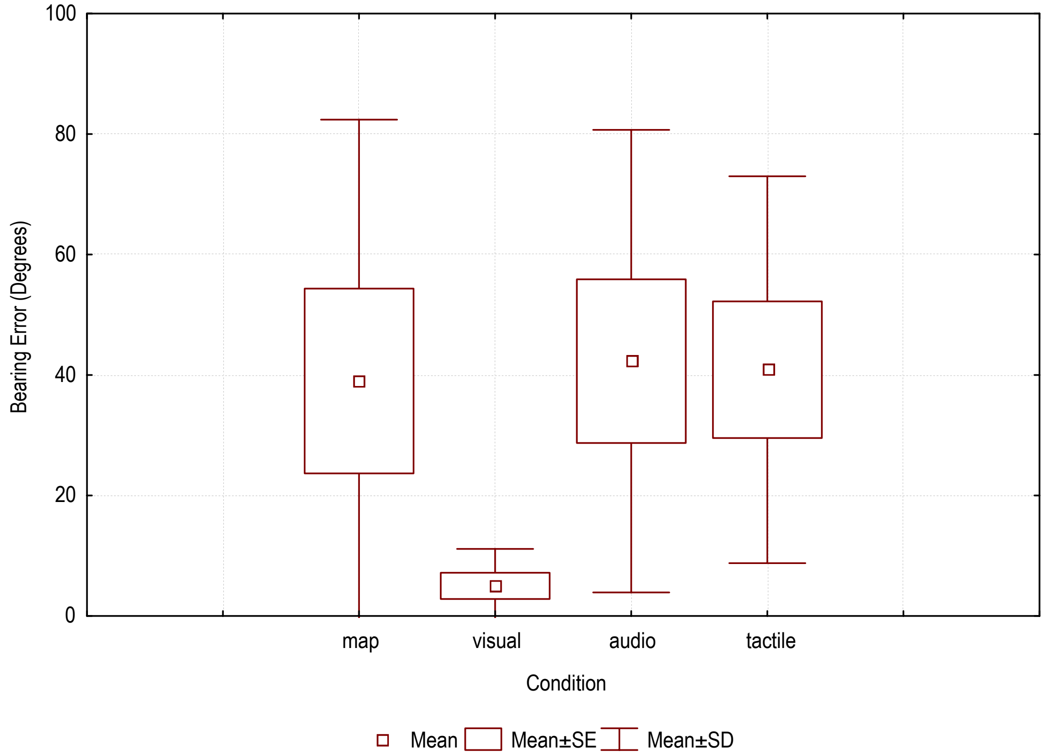
		1 Map	2. Visual	3. Audio	4. Tactile	F values and p values (transformed data)	Differences
Bearing Estimation Error (degrees)	mean ± s.d.	15.3 ± 14.6	5.4 ± 8.6	25.9 ± 21.5	26.1 ± 28.2	F(3,21) = 8.699 p = .0006	1,3,4>2

Figure 13: Bearing Estimation Error—Static Locations

Results indicated that estimations made using the visual system were significantly more accurate than those made with the other systems.

5.2.2 Bearing Estimations to Moving Locations

At the measurement point, participants used their information localization aid (map and compass, visual, audio or tactile) to determine the bearing from their current location to two moving locations on the battlefield (1 Section and 2 Section). Participants were given mission maps indicating the Platoon start point and each Section's objective. The difference between the bearing provided and the actual bearing was calculated and averaged for the two locations. Since the data was not normally distributed, a log transformation was performed on the data, and a repeated-measures ANOVA was conducted on the transformed data with the information localization aid as the within-subjects effect. The results of this analysis and the means and standard deviations (for the untransformed data) are presented in Figure 14.



		1. Map	2. Visual	3. Audio	4. Tactile	F values and p values (transformed data)	Differences
Bearing Estimation Error (degrees)	mean ± s.d.	39.0 ± 43.4	5.0 ± 6.1	42.3 ± 38.4	40.9 ± 32.1	F(3,21) =4.91 p =.01	3,4>2

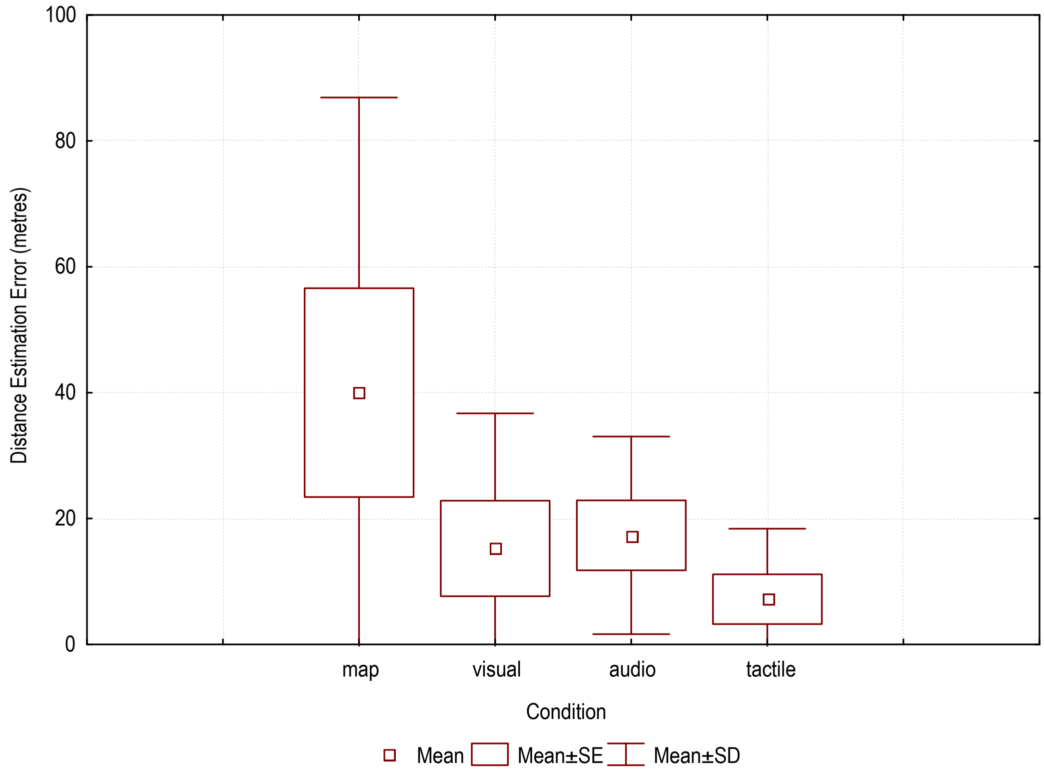
Figure 14: Bearing Estimation Error—Moving Locations

Results indicated that bearing estimations to moving locations were more accurate with visual system than with the audio or tactile condition. Performance was also less variable with the visual system.

An analysis of the log-transformed combined average bearing estimation accuracy to both static and moving locations indicated that the estimations made with the visual system were more accurate than those made with the other systems ($F(3,21)=10.19$, $p=.0002$).

5.2.3 Distance Estimations to Static Locations

At the measurement point, participants used their information localization aid (map and compass, visual, audio or tactile) to determine the Euclidean distance from their current location to two known locations on the battlefield (RV and Enemy). These locations were static and marked on the mission map. The actual distance ranged from 157 metres to 1425 metres, with a mean distance of 574 ± 306 metres. The difference between the distance provided and the actual distance was calculated and averaged for the two locations. Since the data was not normally distributed, a log transformation was performed on the data, and a repeated-measures ANOVA was conducted on the transformed data with the information localization aid as the within-subjects effect. The results of this analysis and the means and standard deviations (for the untransformed data) are presented in Figure 15.



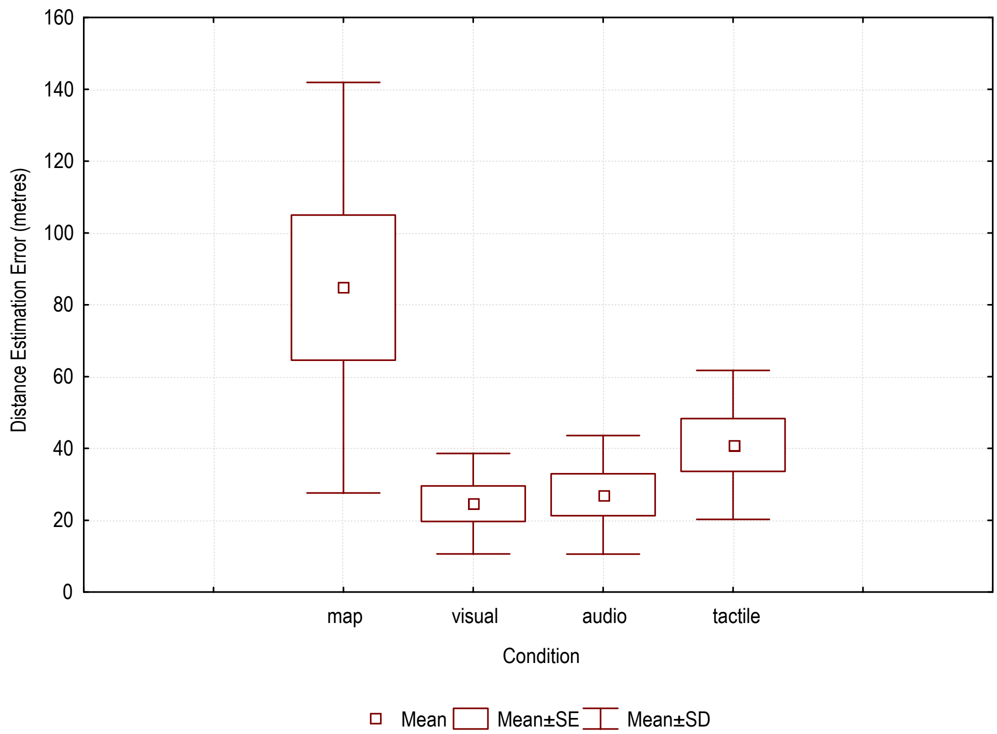
		1 Map	2. Visual	3. Audio	4. Tactile	F values and p values (transformed values)	Differences
Distance Estimation Error (m)	mean ± s.d.	40.0 ± 46.9	15.3 ± 21.5	17.3 ± 15.7	7.2 ± 11.2	F(3,21) =3.43 p =.036	1>4

Figure 15: Distance Estimation Error—Static Locations

Results indicated that the distance estimation error was significantly greater with the map than with the tactile system. There were no other significant differences, however trends indicate greater errors and a larger degree of variability in the accuracy of estimations made using the map and compass baseline method as compared to all the GPS-based methods.

5.2.4 Distance Estimations to Moving Locations

At the measurement point, participants used their information localization aid (map and compass, visual, audio or tactile) to determine the Euclidean distance from their current location to two moving locations on the battlefield (1 Section and 2 Section). The actual distance ranged from 44 metres to 1969 metres, with a mean distance of 847 ± 510 metres. Participants were given mission maps indicating the Platoon start point and each section's objective. The difference between the distance provided and the actual distance was calculated and averaged for the two locations. This mean distance estimation error was subjected to a repeated measures analysis of variance with the information localization aid as the within-subjects effect. The results of this analysis and the means and standard deviations are presented in Figure 16.



		1 Map	2. Visual	3. Audio	4. Tactile	F values and p values	Differences
Distance Estimation Error (m)	mean ± s.d.	84.8 ± 57.2	24.6 ± 14.0	27.1 ± 16.5	41.0 ± 20.7	F(3,21) =6.59 p = .003	1>2,3,4

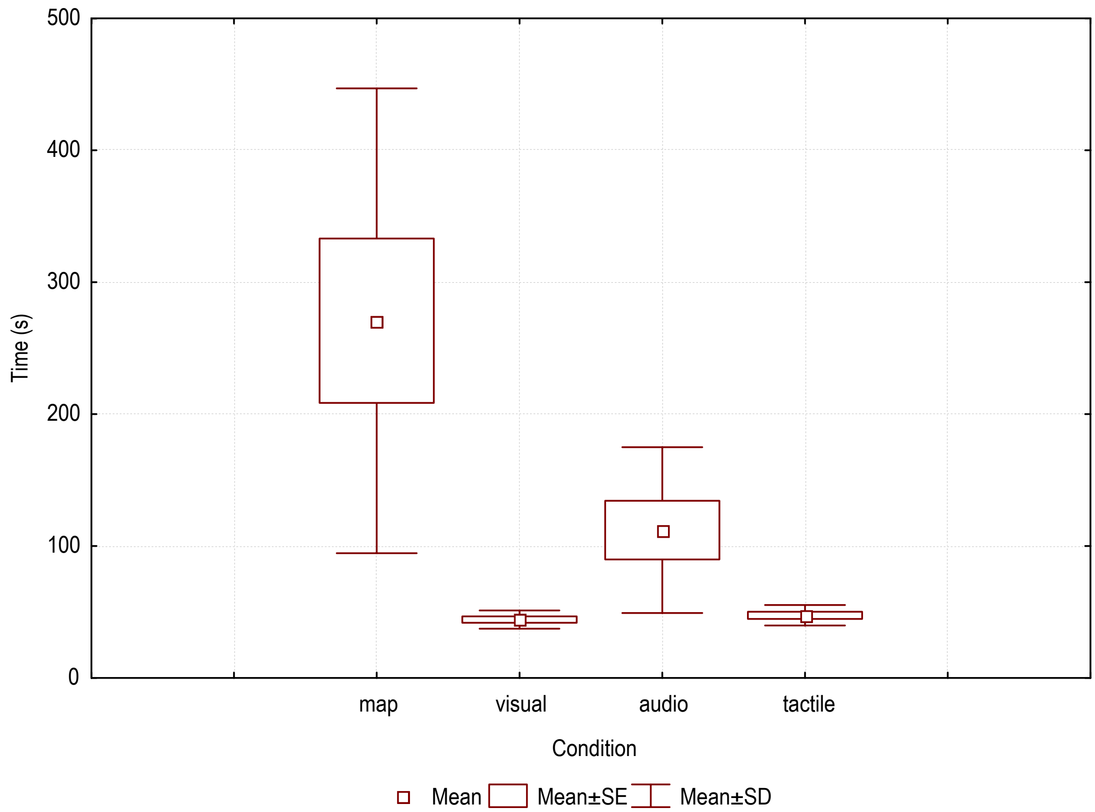
Figure 16: Distance Estimation Error—Moving Locations

Distance estimation errors to moving locations were significantly greater when using the map and compass baseline condition than with all three GPS-based methods.

An analysis of the combined average distance estimation accuracy to both static and moving locations indicated that the estimations made with the map and compass were less accurate than those made with the other systems (F(3,21)=3.65, p=.029).

5.2.5 Time for Measurement Point

The time participants took to provide the distance and bearing estimations to all four locations at the measurement point was recorded by the experimenter. Since the data was not normally distributed, a log transformation was performed on the data, and a repeated-measures ANOVA was conducted on the transformed data with the information localization aid as the within-subjects effect. The results of this analysis and the means and standard deviations (for the untransformed data) are presented in Figure 17.



		1 Map	2. Visual	3. Audio	4. Tactile	F values and p values (transformed values)	Differences
Time for Measurement Point (Seconds)	mean ± s.d.	270 ± 176	44 ± 7	112 ± 63	48 ± 8	F(3,21) =30.00 p = 0.000	1>3>2,4

Figure 17: Time for Measurement Point

The time required to make the distance and bearing estimations was significantly longer with the map and compass baseline condition than with the three GPS-based systems. The audio information localization system also took longer to use than both the visual and tactile systems.

5.3 Questionnaire Results

The following section presents results from the exit questionnaire and the NASA TLX workload questionnaire.

5.3.1 Exit Questionnaire--Information Localization

The exit questionnaire asked participants to rate each method's acceptability for Information Localization according to seven criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 2. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 2: Exit Questionnaire: Information Localization

		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Using the system while stationary	mean ± s.d.	5.8 ± 1.7	6.3 ± 0.7	4.6 ± 1.5	5.0 ± 1.2	$\chi^2(8,3)=9.00$ $p < 0.02929$	2>3
	% unacceptable	12.5%	0%	25.0%	12.5%		
Ease of determining the direction to moving locations of interest	mean ± s.d.	4.5 ± 1.6	6.4 ± 0.7	5.0 ± 1.8	5.5 ± 0.9	$\chi^2(8,3)=8.46$ $p < 0.03736$	2>1,3
	% unacceptable	12.5%	0%	25.0%	0%		
Ease of determining the distance to moving locations of interest	mean ± s.d.	4.5 ± 1.5	6.6 ± 0.5	5.1 ± 1.9	5.4 ± 1.1	$\chi^2(8,3)=11.95$ $p < 0.00756$	2>1,3
	% unacceptable	12.5%	0%	25.0%	0%		
Ease of determining the direction to static locations of interest	mean ± s.d.	6.0 ± 0.5	6.4 ± 0.7	5.0 ± 1.8	5.5 ± 1.1	$\chi^2(8,3)=7.14$ $p < 0.06736$	2>3
	% unacceptable	0%	0%	25.0%	0%		
Ease of determining the distance to static locations of interest	mean ± s.d.	5.9 ± 0.6	6.6 ± 0.5	5.3 ± 1.9	5.8 ± 1.2	$\chi^2(8,3)=9.22$ $p < 0.02643$	2>3
	% unacceptable	0%	0%	25.0%	0%		
Ease of switching between locations with the system	mean ± s.d.	5.4 ± 1.4	6.6 ± 0.5	5.6 ± 1.6	6.0 ± 1.1	$\chi^2(8,3)=5.26$ $p < 0.15345$	None
	% unacceptable	12.5%	0%	12.5%	0%		
Overall Effectiveness Of System for Finding Locations of Interest	mean ± s.d.	5.4 ± 1.1	6.6 ± 0.5	4.6 ± 1.8	5.5 ± 1.1	$\chi^2(8,3)=11.59$ $p < 0.00893$	2>1,3
	% unacceptable	12.5%	0%	25.0%	0%		

Except for "ease of switching between locations with system" the visual system was rated more acceptable than the audio system. The visual system was also rated more acceptable than the map and compass baseline condition for "ease of determining distance to moving location of interest" and "overall effectiveness of system for finding locations of interest". For "ease of determining the distance to moving locations of interest", the visual display was rated more acceptable than all other systems.

The audio system was rated unacceptable by 25% of participants in all categories except "ease of switching between locations with system".

5.3.2 Exit Questionnaire--Terrain Traverse

The exit questionnaire asked participants to rate each method's acceptability for Terrain Traverse according to five criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 3. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 3: Exit Questionnaire: Terrain Traverse Results

		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Ease of walking (while wearing system)	mean ± s.d.	6.9 ± 0.4	5.4 ± 0.5	4.4 ± 1.7	5.6 ± 1.3	$\chi^2(8,3)=14.13$	1>2,3,4
	% unacceptable	0%	0%	25.0%	0%	$p < 0.00273$	4>3
Ease of detecting ground level hazards	mean ± s.d.	6.9 ± 0.4	4.6 ± 1.8	5.5 ± 2.0	6.1 ± 1.0	$\chi^2(8,3)=11.65$	1>2
	% unacceptable	0%	25.0%	12.5%	0%	$p < 0.00867$	
Ease of detecting eye level hazards	mean ± s.d.	6.9 ± 0.4	4.8 ± 1.6	5.5 ± 2.0	6.3 ± 1.0	$\chi^2(8,3)=13.00$	1>2
	% unacceptable	0%	12.5%	12.5%	0%	$p < 0.00464$	
Ease of moving around hazards / obstacles	mean ± s.d.	6.9 ± 0.4	5.1 ± 1.8	5.4 ± 1.9	6.1 ± 1.1	$\chi^2(8,3)=8.88$	1>2
	% unacceptable	0%	12.5%	12.5%	0%	$p < 0.03090$	
Overall Ease Of Terrain Traverse With System	mean ± s.d.	6.9 ± 0.4	5.0 ± 1.7	5.4 ± 1.9	6.1 ± 1.1	$\chi^2(8,3)=10.16$	1>2
	% unacceptable	0%	12.5%	12.5%	0%	$p < 0.01727$	

In the Terrain Traverse category, the map and compass method was rated more acceptable than the visual system for all categories. Furthermore, for "ease of walking (while wearing system)" the map and compass was rated more acceptable than all other systems. The tactile system was also rated more acceptable than the audio system in this category.

The audio system was rated unacceptable by 25% of participants for "ease of walking (while wearing system)". For "ease of detecting ground level hazards" 25% of participants rated the visual system unacceptable. These results are not surprising since both the visual and auditory systems placed an encumbrance on the head and the visual and auditory free-field senses. The map and compass baseline could be stowed during terrain traverse and posed no encumbrance.

5.3.3 Exit Questionnaire--Physical Comfort

The exit questionnaire asked participants to rate each method's acceptability for Physical Comfort according to three criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 4. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 4: Exit Questionnaire: Physical Comfort Results

		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Thermal comfort (heat)	mean ± s.d.	6.9 ± 0.4	5.5 ± 0.5	4.4 ± 1.6	5.6 ± 0.7	$\chi^2(8,3)=17.81$ $p < 0.00048$	1>2,3,4 2,4>3
	% unacceptable	0%	0%	25.0%	0%		
Eyestrain	mean ± s.d.	6.9 ± 0.4	5.4 ± 1.2	6.4 ± 0.7	6.3 ± 1.0	$\chi^2(8,3)=12.59$ $p < 0.00562$	1,3,4>2
	% unacceptable	0%	12.5%	0%	0%		
Overall Physical Comfort while using system	mean ± s.d.	6.9 ± 0.4	5.4 ± 0.7	4.4 ± 1.6	5.6 ± 0.7	$\chi^2(8,3)=16.28$ $p < 0.00099$	1>2,3,4 4>3
	% unacceptable	0%	0%	25.0%	0%		

The map and compass baseline condition was rated significantly more acceptable than all three other systems for "thermal comfort" and "overall physical comfort while using system". Additionally for "thermal comfort", the visual and tactile systems were rated significantly more acceptable than the audio system. For "overall physical comfort while using system" the tactile system was also rated more acceptable than the audio system. Not surprisingly, for eyestrain, all three other systems were rated more acceptable than the visual system.

The audio system was rated unacceptable by 25% of participants for both "thermal comfort" and "overall physical comfort while using system".

5.3.4 Exit Questionnaire--Usability

The exit questionnaire asked participants to rate each method's acceptability for Usability according to four criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 5. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 5: Exit Questionnaire: Usability Results

		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Ease of learning the system	mean ± s.d.	5.9 ± 1.4	6.6 ± 0.5	6.1 ± 1.0	6.5 ± 0.5	$\chi^2(8,3)=2.20$ $p < 0.53195$	None
	% unacceptable	12.5%	0%	0%	0%		
Ease of operating the system	mean ± s.d.	6.3 ± 0.9	6.6 ± 0.5	6.1 ± 1.4	6.6 ± 0.5	$\chi^2(8,3)=0.66$ $p < 0.88101$	None
	% unacceptable	0%	0%	12.5%	0%		
Ease of sensing local surroundings (with system in use)	mean ± s.d.	6.6 ± 0.7	5.3 ± 1.8	3.8 ± 1.5	6.4 ± 0.5	$\chi^2(8,3)=12.54$ $p < 0.00575$	1,2,4>3
	% unacceptable	0%	25.0%	62.5%	0%		
Overall Usability	mean ± s.d.	6.4 ± 0.5	6.0 ± 0.8	4.6 ± 1.4	6.3 ± 0.5	$\chi^2(8,3)=13.13$ $p < 0.00436$	1,2,4>3
	% unacceptable	0%	0%	25.0%	0%		

In the Usability category, the audio system was rated less acceptable than all three other systems for "ease of sensing local surrounding (with system in use)" and "overall usability". There were no other significant differences.

For "ease of sensing local surrounding (with system in use)", the visual system was rated unacceptable by 25% of participants while the audio system was rated unacceptable by 62.5% of participants. For "overall usability", the audio system was rated unacceptable by 25% of participants.

5.3.5 Exit Questionnaire--Compatibility

The exit questionnaire asked participants to rate each method's acceptability for Compatibility according to four criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 6. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 6: Exit Questionnaire: Compatibility

		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Compatibility (interference) with clothing	mean ± s.d.	6.9 ± 0.4	5.4 ± 1.2	4.9 ± 1.0	5.8 ± 1.3	$\chi^2(8,3)=14.00$ $p < 0.00291$	1>2,3,4
	% unacceptable	0%	12.5%	12.5%	12.5%		
Compatibility (interference) with weapon	mean ± s.d.	6.9 ± 0.4	5.5 ± 1.7	5.6 ± 1.1	6.5 ± 0.8	$\chi^2(8,3)=8.02$ $p < 0.04554$	1>2,3
	% unacceptable	0%	12.5%	0%	0%		
Compatibility (interference) with equipment	mean ± s.d.	6.9 ± 0.4	5.6 ± 0.9	4.6 ± 1.3	5.1 ± 1.5	$\chi^2(8,3)=13.19$ $p < 0.00424$	1>2,3,4
	% unacceptable	0%	0%	12.5%	25.0%		
Overall Compatibility Rating	mean ± s.d.	6.9 ± 0.4	5.4 ± 1.2	4.9 ± 0.6	5.5 ± 1.2	$\chi^2(8,3)=14.30$ $p < 0.00252$	1>2,3,4
	% unacceptable	0%	12.5%	0%	0%		

The map and compass baseline was rated significantly more acceptable than all three other systems for compatibility with clothing, equipment and overall compatibility. For "compatibility with weapon" it was rated more acceptable than only the visual and audio systems.

The tactile system was rated unacceptable by 25% of participants for "compatibility with equipment". Again, since the map and compass baseline condition could easily be stowed, it posed no compatibility issues.

5.3.6 Exit Questionnaire--Overall Evaluation of the System

The exit questionnaire asked participants to rate each method's overall acceptability according to six criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 12. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table 7. Items that were rated as unacceptable (i.e. less than four on the seven-point scale) by more than 20% of participants are highlighted in the table.

Table 7: Exit Questionnaire: Overall Evaluation of the Systems

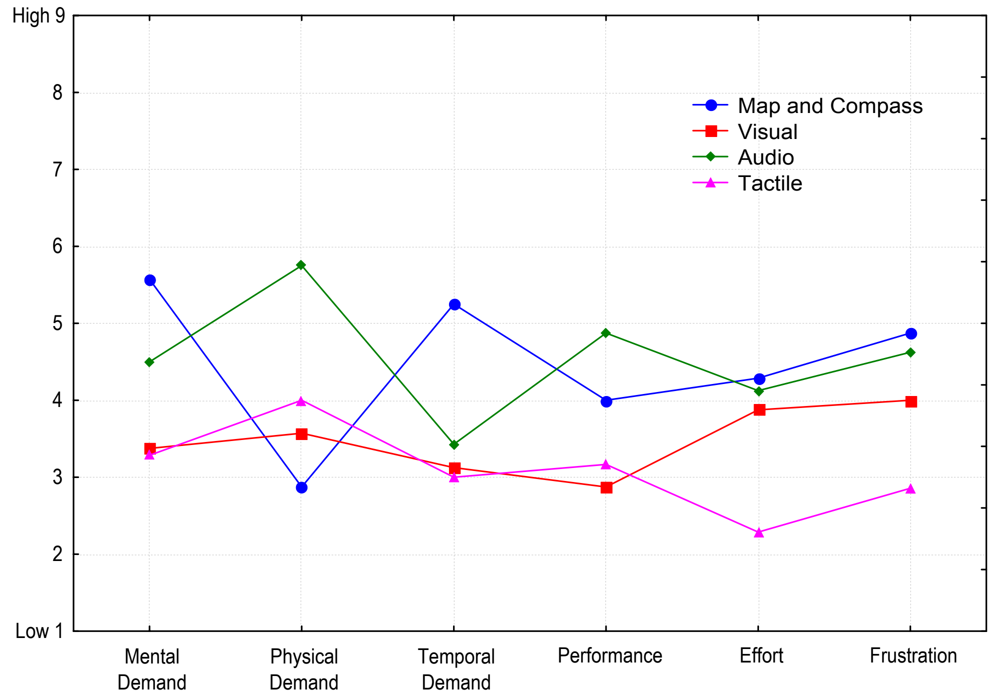
		1. Map	2. Visual	3. Audio	4. Tactile	Chi Squared and p values	Differences
Confidence in the system	mean ± s.d.	6.0 ± 0.8	6.3 ± 0.7	5.0 ± 1.8	5.6 ± 0.9	$\chi^2(8,3)=4.25$ $p < 0.23617$	None
	% unacceptable	0%	0%	12.5%	0%		
Mental workload	mean ± s.d.	5.6 ± 0.7	6.4 ± 0.7	5.4 ± 1.8	5.8 ± 0.9	$\chi^2(8,3)=6.15$ $p < 0.10442$	None
	% unacceptable	0%	0%	12.5%	0%		
Tactical feasibility	mean ± s.d.	6.5 ± 0.5	5.5 ± 1.3	3.1 ± 1.8	4.9 ± 1.6	$\chi^2(8,3)=10.96$ $p < 0.01196$	1,2,4>3 1>4
	% unacceptable	0%	12.5%	75.0%	12.5%		
Accuracy of the system	mean ± s.d.	5.4 ± 0.7	6.6 ± 0.5	5.5 ± 1.4	5.3 ± 1.3	$\chi^2(8,3)=8.03$ $p < 0.04535$	2>1,3,4
	% unacceptable	0%	0%	12.5%	12.5%		
Durability of the system	mean ± s.d.	6.6 ± 0.5	4.9 ± 1.1	3.7 ± 1.6	4.5 ± 1.8	$\chi^2(8,3)=15.13$ $p < 0.00171$	1>2,3,4
	% unacceptable	0%	12.5%	50.0%	25.0%		
Overall Acceptability of System	mean ± s.d.	6.0 ± 0.5	5.9 ± 0.8	3.5 ± 1.4	5.1 ± 1.2	$\chi^2(8,3)=13.5$ $p < 0.00367$	1,2,4>3
	% unacceptable	0%	0%	37.5%	12.5%		

For "tactical feasibility" and "overall acceptability of the system", all other systems were rated significantly more acceptable than the audio system. For "tactical feasibility" the map and compass baseline was also rated more acceptable than the tactile system. For "accuracy of the system", the visual system was rated more acceptable than all other systems. For "durability of the system" the map and compass baseline condition was rated more acceptable than all three other systems. There were no significant differences for "confidence in the system" or "mental workload".

The audio system was rated unacceptable by more than 20% of participants for "tactical feasibility—75%", "durability of the system—50%" and "overall acceptability of the system—37.5%". The visual system was rated unacceptable by 25% of participants for "durability of the system".

5.3.7 Workload Questionnaire

After completing the mission task using each method, participants rated the workload for the task by completing the NASA TLX 10-point workload questionnaire (see Annex A). Six different components of workload were rated: mental demand, physical demand, temporal demand, performance, effort and frustration. Mean ratings were computed for each condition, and an analysis of variance was conducted. The results are summarized in Figure 18.



		1. Map and Compass	2. Visual	3. Audio	4. Tactile	F values p values	Sig. Diffs.
Mental Demand	mean ± s.d.	5.6 ± 2.3	3.4 ± 2.1	4.5 ± 2.6	3.3 ± 2.1	F(3,21)=2.03 p =.14023	None
Physical Demand	mean ± s.d.	2.9 ± 2.4	3.6 ± 2.6	5.8 ± 3.0	4.0 ± 2.4	F(3,21)=2.24 p =.11324	None
Temporal Demand	mean ± s.d.	5.3 ± 2.1	3.1 ± 1.6	3.4 ± 2.1	3.0 ± 1.5	F(3,21)=2.54 p =.08378	None
Performance	mean ± s.d.	4.0 ± 2.0	2.9 ± 1.5	4.9 ± 2.5	3.2 ± 2.5	F(3,21)=2.37 p =.09960	None
Effort	mean ± s.d.	4.3 ± 2.8	3.9 ± 2.4	4.1 ± 1.6	2.3 ± 0.9	F(3,21)=2.70 p =.07199	None
Frustration	mean ± s.d.	4.9 ± 2.4	4.0 ± 1.6	4.6 ± 2.5	2.9 ± 1.5	F(3,21)=1.97 p =.14884	None

Figure 18: NASA TLX Workload Results

There were no significant differences between information visualization methods for any workload items.

5.4 Focus Group

A focus group was held at the conclusion of field testing with all eight subjects participating. In the focus group, each information localization tool was discussed with regards to its strengths and weaknesses for an information localization task. Each system is discussed separately below.

5.4.1 Map and Compass

The participants felt that the map and compass was a proven, reliable solution for terrain traverse and that map and compass skills were a critical part of being an effective soldier. However, without knowing the grid location via radio contact, there was not enough information to find moving entities using a map and compass. If a grid location could be acquired via radio, the participants felt that it would not be difficult to find the location using a map and compass. However, it would be time-consuming.

5.4.2 Visual

Participants felt that the visual display was fast and accurate. They found the forward field of view display very effective, and the information included in the display to be appropriate. However, the virtual retinal display was sometimes washed out by the sun, causing some difficulty in viewing. The participants also commented that they would prefer to be able to move the head-mounted display out of their line of sight when it was not in use. They were concerned that the display could dominate the shooting eye and felt it should be movable from one eye to the other.

5.4.3 Tactile

Participants commented that the tactors sometimes moved out of position causing confusion. They also commented that the tactors used in this experiment were too noisy to be used stealthily. However, overall they found the tactor system quick and effective, and commented that it did not disrupt situation awareness to the same degree as the audio and visual systems.

5.4.4 Audio

The audio system was the least popular system in the focus groups. The participants felt that their sense of hearing could not adapt as well as their vision to the extra information. They felt the audio system was slower than the visual system, and less accurate. Also, they found that the ear cups covering both ears were not acceptable and that using audio for an information localization task would compromise their ability to use their communications systems. They felt the audio system would have to be turned off in order to listen for audio cues in the local environment.

5.4.5 Overall

All the participants indicated they preferred the augmented reality visual system to the three other systems. They felt that a visual system that could be displayed to the eye with the push of a button when needed would be ideal. When not in use, the system should be out of the field of view. Participants expressed concern with the use of all three GPS-based systems for use when in a prone position. In particular, the tactile system would be difficult to relate to the terrain if the user was not in an upright position.

6. Discussion and Conclusions

This section presents a summary and discussion of the major results of this study. It also includes recommendations for improving the systems used and areas of further research.

6.1 Summary and Discussion of Results

Table 8 summarizes the major results of this experiment:

Table 8: Summary of Major Results

	Measure	Significant Differences
Mission Performance Results	**Bearing Estimation Error (Static Locations)**	map, audio, tactile> visual
	Bearing Estimation Error (Moving Locations)	audio, tactile> visual
	Combined Static and Moving Bearing Estimation Error	map, audio, tactile> visual
	Distance Estimation Error (Static Locations)	map>tactile
	Distance Estimation Error (Moving Locations)	map>visual, audio, tactile
	Combined Static and Moving Distance Estimation Error	map>visual, audio, tactile
	Time for Measurement Point	map> audio > visual, tactile
Exit Questionnaire Results	**Overall Effectiveness for Information Localization**	visual> map, audio
	Overall Ease of Terrain Traverse with System	map>visual
	Overall Physical Comfort	map>visual, audio, tactile tactile>audio
	Overall Usability	map, visual, tactile>audio
	Overall Compatibility	map>visual, audio, tactile
	Overall Acceptability of the System	map, visual, tactile>audio

Map and Compass Baseline

The participants in this experiment were very experienced and familiar with the map and compass condition. They found this baseline condition to be acceptable for a localization task, although they did indicate on the exit questionnaire that the visual system was preferred over the map and compass. This condition was consistently rated most acceptable for items relating to physical comfort, usability and compatibility. These results are not surprising as the map and compass method was much more familiar to the soldiers participating in this experiment than any of the other methods used and these items could be easily stowed when not in use. There were no items where the baseline condition was rated unacceptable by more than 20% of participants.

In terms of performance, distance estimations to moving locations were worse with the map and compass than with all other systems. Trends indicate that bearing estimations were also less accurate with this baseline system, but this difference was only significant as compared to the visual condition. There was also much more variability in performance with this system than with the GPS-based systems. The time required to determine the distance and bearing measurements was significantly higher with the map and compass than with the other systems.

Audio

The audio system was the least preferred of the systems tested. Participants indicated that the fully occluding ear cups were hot and uncomfortable and severely limited their situation awareness. The audio system was consistently rated the least acceptable on the exit questionnaire. Participants commented that they found the audio tones annoying and difficult to use to determine the bearing to a location. The audio system was also rated unacceptable by more than 20% of participants on the exit questionnaire in eight areas:

- Ease of walking (while wearing the system),
- Thermal comfort,
- Overall physical comfort while using the system,
- Ease of sensing local surroundings (with system in use),
- Overall usability,
- Tactical feasibility,
- Durability of the system, and,
- Overall acceptability

Because the 3D audio system used a generic Head-Related Transfer Function (HRTF), the HRTF may not have been well suited for all participants in the experiment. Further research using participant-specific HRTFs may alleviate this problem. Also, the audio system in this experiment used tones of varying rate and pitch to pinpoint a location. Systems are now available that can display voices in a 3D environment. For example, a soldier may be able to hear his Section Commander's voice in his communications system coming from the actual direction where the Section Commander is located even if they are separated by long distances.

Tactile

The tactile system was generally considered acceptable by participants, although not as accurate as the visual system. The tactile system had the advantage of not obstructing the participant's field of view or interfering with his ability to traverse terrain

The tactile system was rated unacceptable by more than 20% of participants for the following two items on the exit questionnaire:

- Compatibility (interference) with equipment.
- Durability of the systemA ruggedized tactor system designed for military use, could eliminate these concerns. ***Visual***

Overall results indicate that the visual system was the preferred system for the information localization task. Performance results indicate that bearing estimations were best with the visual system. Although the differences were not significant at the $p < .05$ level, trends also indicate that distance estimations and time required to use the system were also best with the visual display system.

The visual system was rated unacceptable by more than 20% of participants for the following two items on the exit questionnaire:

- Ease of detecting ground level hazards
- Ease of sensing local surroundings (with system in use),

The area where the visual display had the most difficulty was in the ease of terrain traverse while wearing the system. Participant soldiers commented that even though the display was see-through, it still obstructed their field of view and distracted their attention from the surrounding environment. Participants indicated that they would prefer a display that could be moved out of their field of view when not in use, and easily transferred from the left to the right eye. The system was also washed out by bright sunlight--a daylight readable display is necessary.

6.2 Overall Recommendations

The results of this research indicate that providing GPS-based information to soldiers is an improvement over a map and compass-based information localization system. Of the three GPS-based systems tested, the augmented reality visual display was preferred. However, the information must be conveyed to the soldier in a way that does not compromise his situation awareness to an unacceptable degree. If a soldier is in a situation where his visual sense is already overloaded, localization information displayed using a tactile method may be preferable. Improvements to an audio method including non-occluding ear cups and customisable 3D sound could make the audio method of information localization more viable. Transparent hearing capabilities may allow improved situation awareness while wearing full ear-cups.

6.3 Further Work

This section presents some areas of further work that are suggested by the results of this study.

6.3.1 Integration of Helmet-Mounted Systems

Because so many new types of technology are being considered for addition to the Canadian Infantry helmet, work is required to integrate all systems together for a compatible overall helmet system. An information localization system should be integrated so that it is combined with (or at least, does not interfere with) night vision goggles, sighting systems, radio communication systems, vision, hearing and ballistic protection systems, and NBC protection systems. Research into the integration of these systems is recommended.

7. References

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Annex 1: Questionnaires

***

Workload – NASA TLX Questionnaire

PARTICIPANT ID# : ________

RUN #: 1 ☐ 2 ☐ 3 ☐ 4☐

CONDITION: **Map & Compass** ☐ **Visual** ☐ **Audio** ☐ **Tactile** ☐

Section A: Rate the display by marking each scale at the point which matches your experience. Each line has two endpoint descriptors to help describe the scale. Please consider your responses to these scales carefully.

MENTAL DEMAND (thinking, deciding, searching, remembering)

Low (easy, simple) — **High** (demanding, complex)

PHYSICAL DEMAND (controlling, operating, activating)

Low (easy, restful) — **High** (demanding, laborious)

TEMPORAL DEMAND (time pressure)

Low (leisurely) — **High** (frantic)

PERFORMANCE (how successful and how satisfied were you with performing this task?)

Good — **Poor**

EFFORT (how hard did you have to work, both mentally and physically?)

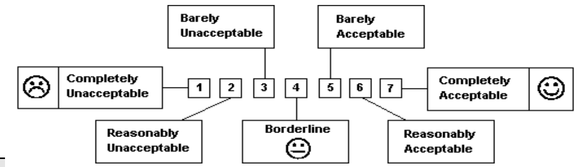
Low — **High**

FRUSTRATION

Low (gratified, complacent) — **High** (discouraged, annoyed)

Section B: Comments (Use back of page if required)

Exit Questionnaire



Participant ID#: ______________ DATE:_________________

	MAP AND COMPASS	**VISUAL**	**AUDIO**	**TACTILE**
INFORMATION LOCALIZATION	**Acceptance Rating** ☹ 😐 ☺ **1 2 3 4 5 6 7**	**Acceptance Rating** ☹ 😐 ☺ **1 2 3 4 5 6 7**	**Acceptance Rating** ☹ 😐 ☺ **1 2 3 4 5 6 7**	**Acceptance Rating** ☹ 😐 ☺ **1 2 3 4 5 6 7**
Using the system while stationary	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of determining the direction to the location of interest	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of determining the distance to the location of interest	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of determining the direction to static locations of interest	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of determining the distance to static locations of interest	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of switching between locations with the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Effectiveness Of System for Finding Locations of Interest	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

	MAP AND COMPASS	VISUAL	AUDIO	TACTILE
TERRAIN TRAVERSE	**Acceptance Rating** ☹ 1 2 3 😐 4 5 6 ☺ 7	**Acceptance Rating** ☹ 1 2 3 😐 4 5 6 ☺ 7	**Acceptance Rating** ☹ 1 2 3 😐 4 5 6 ☺ 7	**Acceptance Rating** ☹ 1 2 3 😐 4 5 6 ☺ 7
Ease of walking (while wearing system)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of detecting ground level hazards	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of detecting eye level hazards	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of moving around hazards / obstacles	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Ease Of Terrain Traverse With System	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
PHYSICAL COMFORT				
Thermal comfort (heat)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Eyestrain	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Physical Comfort while using system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

Exit Questionnaire

	MAP AND COMPASS	VISUAL	AUDIO	TACTILE
USABILITY	**Acceptance Rating** ☹ 😐 ☺ 1 2 3 4 5 6 7	**Acceptance Rating** ☹ 😐 ☺ 1 2 3 4 5 6 7	**Acceptance Rating** ☹ 😐 ☺ 1 2 3 4 5 6 7	**Acceptance Rating** ☹ 😐 ☺ 1 2 3 4 5 6 7
Ease of learning the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of operating the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of sensing local surroundings (with system in use)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Usability	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
COMPATIBILITY				
Compatibility (interference) with clothing	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility (interference) with weapon	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility (interference) with equipment	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Compatibility Rating	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

Exit Questionnaire

	MAP AND COMPASS							VISUAL							AUDIO							TACTILE						
OVERALL	Acceptance Rating							Acceptance Rating							Acceptance Rating							Acceptance Rating						
	☹ 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
Confidence in the system	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Mental workload	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Tactical feasibility	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Accuracy of the system	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Durability of the system	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Overall Acceptability of System	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Additional Comments

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Evaluation of Visual, Auditory and Tactile Displays of GPS−Based Localization Information for Soldiers on the Battlefield (U)
Évaluation d'Affichages Visuels, Sonores et Tactiles d'Information de Localisation GPS pour les Soldats sur le Champ de Bataille

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Heather J. Colbert; David W. Tack

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(U) This report describes an investigation of various displays of GPS−based position, bearing and distance information using three systems: 1) an augmented reality visual display in a head−mounted virtual retinal device; 2) a 3D audio system using tone pitch and frequency cues; and 3) an eight−tactor chest−distributed tactile system. These systems were compared to a map and compass baseline condition for localizing both stationary and moving battlefield entities within the context of platoon attack missions. Performance measures included distance and bearing estimation accuracy, and time required for distance and bearing estimations. Acceptability data were collected in the form of workload questionnaires, exit questionnaires, focus groups and human factors observer assessments.

Overall, GPS− based navigation information systems were found to provide advantages over a map−and−compass−based system. Of the three systems tested, the visual display was preferred; however, it tended to compromise the soldier's situation awareness. Performance trends also indicated that the bearing and distance estimations and time required to use the system were best with the visual display system. If a soldier is in a situation where his visual sense is already overloaded, localization information displayed using a tactile method may be preferable. Improvements to an audio method including non−occluding ear cups and customisable 3D sound could make the audio method of information localization viable.

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(U) Soldier Information Requirements Technology Demonstration Project; SIREQ TD; Visual displays; Auditory displays; Tactile Displays; GPS; Localization Information; mission planning; wayfinding; tactors; navigation; 3D sound; 3D audio; haptic displays; situation awareness