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EXAMINATION OF HEAD-MOUNTED, HEADS-UP AND WEAPON-MOUNTED VISUAL DISPLAYS FOR INFANTRY SOLDIERS

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Abstract

This experiment built on previous SIREQ-TD studies by quantifying the performance and utility of head-mounted, heads-up and weapon-mounted visual displays during a wayfinding and target detection task. A four-day field trial took place at Ft. Benning, Georgia with sixteen regular force infantry soldiers participating. Participant soldiers navigated 1200-metre routes through wooded terrain using an enhanced wayfinding aid in each of three display conditions. As a secondary task, participants were required to detect and engage targets on their route. Three configurations for an enhanced wayfinding aid were investigated: 1) A head-mounted occluded display featuring a wayfinding display generated by the Future Infantry Navigation Device (FIND) system. 2) A head-mounted non-occluded virtual retinal display featuring a wayfinding display generated by the FIND system. 3) A weapon mounted Garmin e-trex GPS on the "Navigate" page and showing the "Big Compass" display.

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 strongly preferred by the participants.

Résumé

Cette expérience complète les études précédentes de SIREQ-TD en quantifiant le rendement et la fonctionnalité d'afficheurs visuels montés sur casque, de type tête haute et montés sur arme durant une tâche d'orientation et de détection d'objectif. Seize fantassins de la Force régulière ont pris part à un essai sur le terrain de quatre jours à Fort Benning, en Géorgie. Les fantassins participants ont parcouru des routes de 1 200 mètres sur terrain boisé en utilisant une aide à l'orientation améliorée dans chacune des trois conditions d'affichage. Les participants avaient comme tâche secondaire de détecter et d'engager les objectifs sur leur route. Trois configurations d'aide à l'orientation améliorée ont été examinées : 1) afficheur occlus monté sur casque présentant des données d'orientation générées par le système de navigation de l'Infanterie de l'avenir (SNIA); 2) afficheur rétinien virtuel non occlus monté sur casque présentant des données d'orientation générées par le SNIA; 3) GPS Garmin e-trex monté sur arme affichant la page de navigation avec une grosse boussole.

Bien que les résultats des questionnaires et du groupe de discussion aient indiqué la préférence des participants pour l'afficheur monté sur arme plutôt que pour les deux afficheurs montés sur casque, les données de rendement n'ont indiqué aucune différence significative entre les trois afficheurs pour ce qui est du rendement d'engagement des objectifs. De plus, il n'existait que de faibles différences de rendement d'orientation entre les trois afficheurs. Des deux afficheurs montés sur casque, l'afficheur rétinien virtuel était celui que préféraient nettement les participants.

Executive Summary

This experiment built on previous SIREQ-TD studies by quantifying the performance and utility of head-mounted, heads-up and weapon-mounted visual displays during a wayfinding and target detection task. A four-day field trial took place at Ft. Benning, Georgia with sixteen regular force infantry soldiers participating. Participant soldiers navigated 1200-metre routes through wooded terrain using an enhanced wayfinding aid in each of three display conditions. As a secondary task, participants were required to detect and engage targets on their route. Three configurations for an enhanced wayfinding aid were investigated:

1) A head-mounted occluded display featuring a wayfinding display generated by the Future Infantry Navigation Device (FIND) system.
2) A head-mounted non-occluded virtual retinal display featuring a wayfinding display generated by the FIND system.
3) A weapon mounted Garmin e-trex GPS on the "Navigate" page and showing the "Big Compass" display.

Objective performance measures were collected in the following categories:

- Time to Complete Route
- Extra Distance Travelled
- Root Mean Square Error Deviation
- Accuracy of Waypoint Estimation
- Targets Engaged

Subjective data was collected in the form of NASA TLX workload questionnaires, exit questionnaires, an exit focus group and human factors observer assessments.

Performance data was subjected to a repeated measures ANOVA and post-hoc Duncan tests to identify significant differences. Questionnaire data was subjected to a Friedman's ANOVA. For wayfinding performance data, significant differences occurred in only two categories, Extra Distance Travelled and Waypoint Estimation Error. For Extra Distance Travelled, participants travelled significantly more extra distance with the occluded display as compared to the other two displays.

For Waypoint Estimation Error, the error with the weapon-mounted display was significantly more than with the two head-mounted displays. However, the mean waypoint accuracy error with all three displays was less than 20 metres, which is acceptable for infantry applications.

While questionnaire and focus group results indicated the participants' preference for the weapon-mounted display over the two head-mounted displays for target engagement, performance results indicated no significant difference between the three displays in target engagement performance.

Overall questionnaire and focus group results indicate that the weapon-mounted display was the preferred choice of participants, followed by the non-occluded virtual retinal display. The occluded display was the least preferred display. Many participants indicated their concern with placing extra weight on the head. If a helmet-mounted wayfinding system could be incorporated into other helmet-mounted systems (such as night vision goggles or radio communications systems), they would be considered more acceptable. Further research is recommended in this area.

Other additional research recommended includes:

- Research into the integration of helmet-mounted systems.
- Research into the weight limits and weight distribution of attachments to infantry helmets.
- An analysis of other types of visual displays.
- An analysis of other (Non-Wayfinding) information that can be presented to soldiers in visual displays.
- An investigation of the ability to update wayfinding displays in real-time.

Sommaire

Cette expérience complète les études précédentes de SIREQ-TD en quantifiant le rendement et la fonctionnalité d'afficheurs visuels montés sur casque, de type tête haute et montés sur arme durant une tâche d'orientation et de détection d'objectif. Seize fantassins de la Force régulière ont pris part à un essai sur le terrain de quatre jours à Fort Benning, en Géorgie. Les fantassins participants ont parcouru des routes de 1 200 mètres sur terrain boisé en utilisant une aide à l'orientation améliorée dans chacune des trois conditions d'affichage. Les participants avaient comme tâche secondaire de détecter et d'engager les objectifs sur leur route. Trois configurations d'aide à l'orientation améliorée ont été examinées :

1) afficheur occlus monté sur casque présentant des données d'orientation générées par le système de navigation de l'Infanterie de l'avenir (SNIA);
2) afficheur rétinien virtuel non occlus monté sur casque présentant des données d'orientation générées par le SNIA;
3) GPS Garmin e-trex monté sur arme affichant la page de navigation avec une grosse boussole.

Des mesures de rendement visé ont été effectuées dans les catégories suivantes :

- Temps pour parcourir la route
- Distance supplémentaire parcourue
- Erreur quadratique moyenne de déviation
- Précision d'estimation des points de cheminement
- Objectifs engagés

Des données subjectives ont été recueillies au moyen de questionnaires sur la charge de travail TLX de la NASA, de questionnaires finaux ainsi que d'évaluations finales du groupe de discussion et d'un observateur des facteurs humains.

Les données de rendement ont été soumises à une analyse de la variance (ANOVA) de mesures répétées et à des tests post-hoc de Duncan visant à déterminer les différences significatives. Les données des questionnaires ont été soumises à une analyse de la variance de Friedman. Pour ce qui est des données de rendement d'orientation, des différences significatives se sont produites dans deux catégories seulement : la distance supplémentaire parcourue et l'erreur d'estimation des points de cheminement. En ce qui a trait à la distance supplémentaire parcourue, les participants ont franchi une distance supplémentaire beaucoup plus grande avec l'afficheur occlus qu'avec les deux autres afficheurs.

Quant à l'erreur d'estimation des points de cheminement, elle était nettement supérieure avec l'afficheur monté sur arme qu'avec les deux afficheurs montés sur casque. Les trois afficheurs présentaient toutefois une erreur moyenne inférieure à 20 mètres pour ce qui est de la précision des points de cheminement, ce qui demeure acceptable pour les applications d'infanterie.

Bien que les résultats des questionnaires et du groupe de discussion aient montré la préférence des participants, au moment de l'engagement d'un objectif, pour l'afficheur monté sur arme plutôt que

pour les deux afficheurs montés sur casque, les résultats de rendement n'ont révélé aucune différence significative entre les trois afficheurs du point de vue de l'engagement des objectifs.

Les résultats globaux du questionnaire et du groupe de discussion ont indiqué que les participants préféraient l'afficheur monté sur arme, puis l'afficheur rétinien virtuel non occlus. L'afficheur occlus venait en dernier lieu. Bon nombre de participants ont souligné leur réticence à se placer un poids supplémentaire sur la tête. S'il était possible d'incorporer un système d'orientation monté sur casque à d'autres systèmes montés sur casque (comme des lunettes de vision nocturne ou des systèmes de radiocommunications), cette solution leur apparaîtrait plus acceptable. On recommande d'effectuer des recherches plus approfondies sur cet aspect.

Voici d'autres secteurs de recherche recommandés :

- Recherche sur l'intégration de systèmes montés sur casque.
- Recherche sur les limites et la distribution du poids des accessoires de casque d'infanterie.
- Analyse d'autres types d'afficheurs visuels.
- Analyse d'autre information (n'ayant pas trait à l'orientation) pouvant être présentée sur les afficheurs des soldats.
- Étude de la capacité de mise à jour des afficheurs d'orientation en temps réel.

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List of Acronyms

The following acronyms are used in this report:

ANOVA	Analysis of Variance
FIND	Future Infantry Navigation Device
GPS	Global Positioning System
DGPS	Differential Global Positioning System
HMD	Head (or Helmet) Mounted Display
NVG	Night Vision Goggle
VRD	Virtual Retinal Display

1. Background

The SIREQ TD 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.

Several countries are using occluded head-mounted displays in their future soldier system (e.g. US Land Warrior). A study conducted by Glumm et al (1998) indicated some advantages to helmet-mounted 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 an occluded 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 auditorily in verbal messages. The results indicated that differences between the visual and auditory displays were not statistically significant for navigation, target acquisition, workload, and cognitive performance.

Both of these studies indicate that helmet-mounted visual information may be an appropriate way to display navigation information. However, the display format of this visual information needs further investigation. The comparative usefulness of information displayed directly to the eye versus weapon-mounted information also has not been investigated.

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, 2002) These studies concluded that a visual display may be ideal for navigation information, however they questioned the operational feasibility of an occluded HMD to display visual information. These studies suggested that non-occluded helmet-mounted displays or weapon-mounted displays may present some operational advantages.

The experiment described in this report aimed to build on the previous SIREQ-TD studies by quantifying the performance and utility of head-mounted, heads-up and weapon-mounted visual displays during a wayfinding and target detection task and identifying features of an optimal visual display for infantry soldiers.

2. Aims

The aim of this experiment was to compare the utility of head-mounted, heads-up and weapon-mounted visual displays for infantry soldiers.

The goals of this experiment included:

- Quantifying the performance and utility of head-mounted, heads-up and weapon-mounted visual displays during a wayfinding and target detection task for the SIREQ-TD project.
- Identifying features of an optimal visual display for infantry soldiers for the SIREQ-TD project.

3. Method

This section provides an overview of the method used in this experiment, details the approach taken in the field trial, explains the equipment and describes the experimental measures used.

3.1 Overview

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

A four-day field trial took place at Ft. Benning, Georgia from 10-13 November, 2002 with sixteen regular force infantry soldiers. The trial schedule is shown in Table 1 below.

Table 1: The four-day trial schedule

10-13 November 2002			
November 10	**November 11**	**November 12**	**November 13**
Session 1: (Subjects 1 through 8)	Sessions 2 and 3: (Subjects 1 through 8)	Sessions 1 and 2: (Subjects 9 through 16)	Session 3: (Subjects 9 through 16) Focus Group (Subjects 1 through 16)

Participant soldiers navigated 1200-metre routes through wooded terrain using an enhanced wayfinding aid in each of three display conditions. As a secondary task, participants were required to detect and engage targets on their route while wayfinding. One route leg required the participant to navigate an unexpected obstacle marked with mine tape.

Three configurations for an enhanced navigation aid were investigated:

- A head-mounted occluded display featuring a wayfinding display generated by the Future Infantry Navigation Device (FIND) system.
- A head-mounted non-occluded virtual retinal display featuring a wayfinding display generated by the FIND system.
- A weapon mounted Garmin e-trex GPS on the “Navigate” page and showing the “Big Compass” display.

The FIND system was used to generate the display and track performance for the first two conditions. In the third (weapon-mounted) condition, it was used to track performance only.

Three different open country route plans were used and each participant used a different route for each condition to ensure that the learning effects of previous missions were minimized.

Human factors tests assessed wayfinding performance, target detection, and user assessments of wayfinding modality effectiveness and workload. Data collection included questionnaires, focus groups, performance measures and HF observer assessments.

3.2 The FIND System

This experiment used the Future Infantry Navigation Device (FIND) system to generate wayfinding displays and capture wayfinding performance data. FIND was developed by Humansystems Incorporated in conjunction with Oerlikon Aerospace. The system consisted of a small laptop computer, a global positioning system (GPS) receiver, a DGPS beacon receiver, an electronic compass, and the associated power supplies (see Figures 1 and 2). Position coordinates of waypoints were pre-programmed into the computer. During a mission, the participant's location and orientation, as measured by the GPS and the electronic compass, were updated once every second. The bearing of the participant's head, measured by the electronic compass mounted to the helmet, was updated 10 times every second.

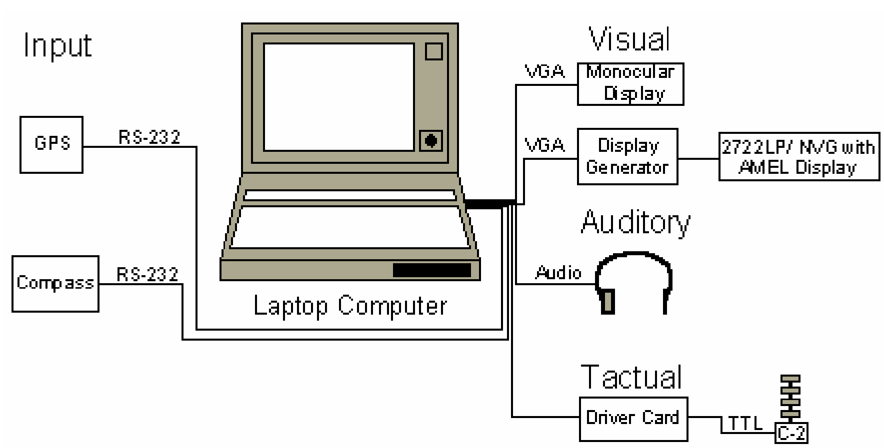


Figure 1: FIND System Schematic

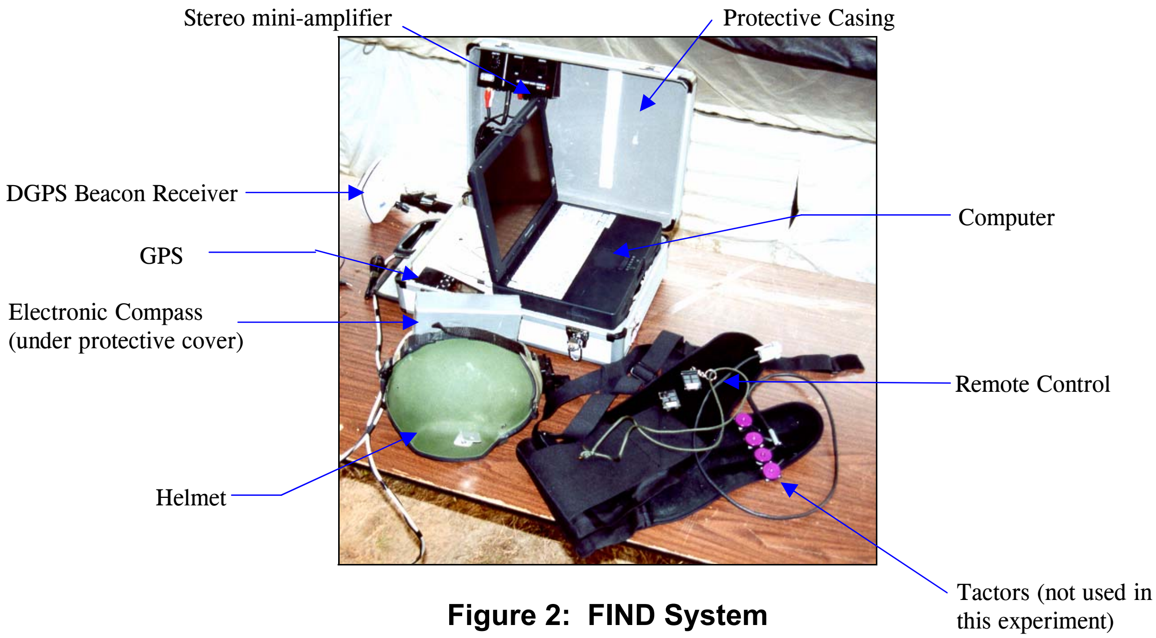


Figure 2: FIND System

The FIND system worked by relating the user's own location (GPS) and facing direction (electronic compass on head) to the next waypoint (see Figure 3). The difference between the facing direction and the waypoint bearing produced the offset bearing for display in the visual displays. Similarly, the distance from the user's own location to the waypoint was continuously updated to enable the system to alert the user when the waypoint location was reached.

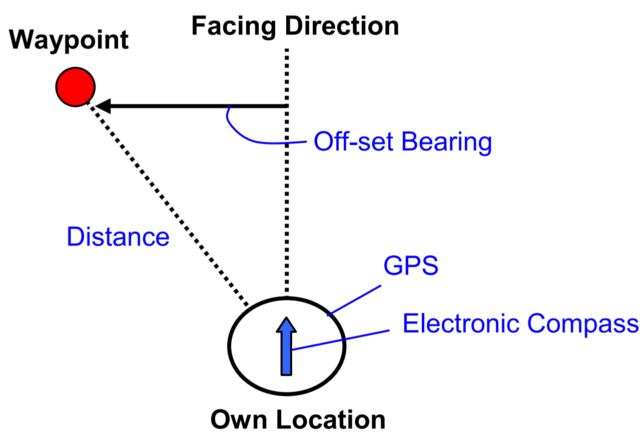


Figure 3: Wayfinding Output Data

The FIND system was configured to enable the same base wayfinding system configuration to be used for each display modality. The base system performed all of the necessary navigational processes and output the off-set bearing and distance parameters required for each of the display types. For each experimentation trial, the appropriate display type was plugged into a laptop (worn in a small day pack), the GPS track was captured for each experimentation route.

In each case, the participant's head was used as the platform for determining the participant's facing direction. With the electronic compass mounted to the participant's headgear, the participant was able to visually scan the way ahead while receiving directional cues from the visual display.

Although the FIND system was continuously operating during each experimentation route, the participant controlled the display of wayfinding data, since a continuous display could result in a significant distraction for other soldiering tasks. The controller switch was attached to the participants' weapons to enable him to activate the display as required to update the wayfinding status, without releasing hold of his weapon.

The participant observed the visual display to determine the distance to the waypoint. When the participant indicated he had reached his waypoint, a human factors observer, switched the system to the next waypoint. At the completion of the route, the human factors observer saved the track captured for that route in a data file stored on the laptop hard-drive for subsequent analysis.

3.3 Display Conditions

Three different display conditions were investigated in this experiment, an occluded head-mounted display, a non-occluded heads-up virtual retinal display and a weapon-mounted display.

3.3.1 Occluded Head-Mounted Display: M1 Personal Viewer

The occluded head-mounted display used in this experiment was the monocular M1 Personal Viewer (Figure 4). The fully occluded M1 Personal Viewer provided a 320 x 240 gray scale display. The M1 system consisted of a head-mounted display and a drive electronics assembly. It was connected to the FIND system computer using a standard VGA connector.

Operational Temperature Range	0 °C to +70 °C
Weight	300g
Video Resolution	320 x 240

Figure 4: M1 Personal Viewer

3.3.2 Heads-Up Display: Microvision Nomad

The virtual retinal display Nomad by Microvision (see Figure 5) was used as the heads-up display 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 virtual retinal display 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 and 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 moves back to the other side and down slightly to draw the next line of the image.(www.microvision.com)

Operational Temperature Range	0 °C to 45 °C
Weight (head-worn display)	502 g
Video Resolution	800 x 600

Figure 5: Microvision Nomad Virtual Retinal Heads-Up Display

3.3.3 Weapon-Mounted Display

The weapon mounted display consisted of a Garmin e-trex Summit GPS unit with a digital compass (see Figure 6) set on the "Navigate" page and showing the "Big Compass" display. The GPS unit was mounted on the participant's weapon on top of the optical scope. The FIND system was used for tracking purposes only in this condition.

Operational Temperature Range	-15°C to 70°C
Weight (with batteries)	150g

Figure 6: Garmin e-trex Summit GPS

The Garmin e-trex was attached to the rifle on top of the optical scope as shown in Figure 7.

Figure 7: The Weapon-Mounted Garmin e-trex Summit GPS

3.4 The Software Display

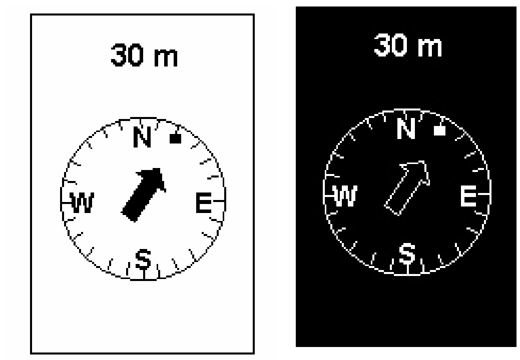


Figure 8: a) the occluded display and b) the VRD display

The software display used in this experiment was based on the Garmin e-trex Summit GPS display in digital compass mode. The display consisted of an ego-centric compass display with cardinal directions (N, S, E, W) marked on the display. The waypoint was indicated by a small square on the display. The distance in metres was shown in the centre of the top of the display. A “black on white” display was used for the occluded display condition while, a “white on black” display was used for the see-through virtual retinal display condition. When displayed in the Nomad VRD, the white on black appeared as red writing on a clear background. The displays are shown in Figures 8 a) and b).

3.5 Procedure

In each experimental session, a participant navigated a five-leg route using one of the three display types. A sample route is shown in Figure 9.

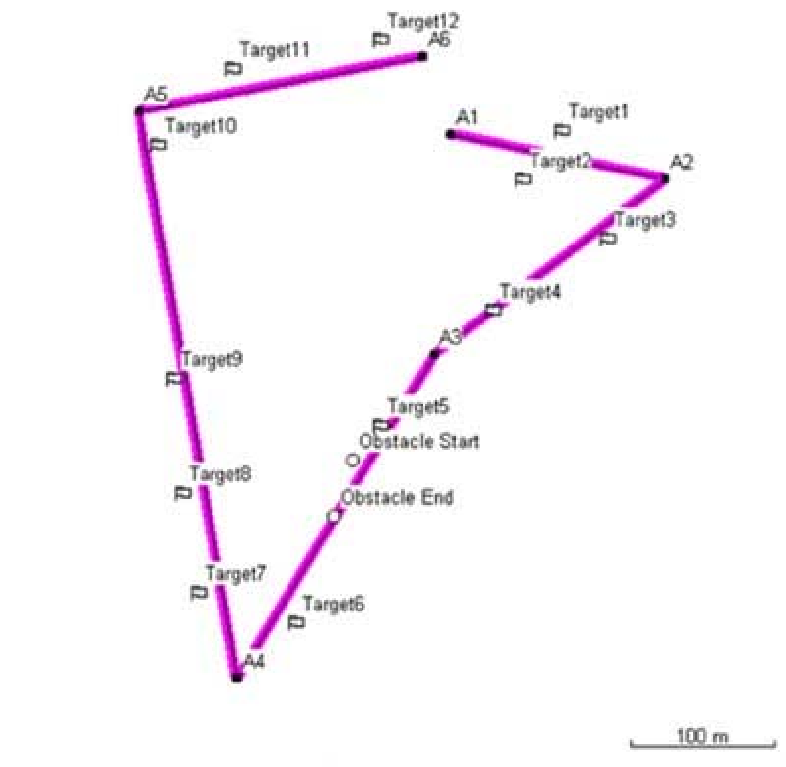


Figure 9: A Sample Route

One human factors experimenter was assigned to each participant for the duration of the session. In preparation for each experimental session, the experimenter configured the FIND system for the correct display type and route. The participant's remote control for the FIND system was attached to the participant's weapon. The participant donned the FIND system backpack and appropriate display and the experimenter held the experimenter remote control for the FIND system. The participant then navigated to two test waypoints to ensure his understanding of the system and the proper functioning of all equipment. The participant then began navigation of the route with the experimenter following. When the participant pressed a button on his remote control, it brought up the wayfinding display on his display presentation device. Pressing the button again turned the display off. Note this step was not necessary for the weapon-mounted display, as it was kept constantly on.

As the participant encountered targets, he engaged them with a double-tap (two shots in quick succession). The experimenter logged target engagements on the FIND system by pressing a button on his remote control. There were 12 targets per route.

When the participant felt he had reached each waypoint according to his wayfinding display aid, he indicated "waypoint reached" to the experimenter. The experimenter then used his remote control to update the FIND system for the next waypoint, or reset the e-trex Summit GPS to the next point in the weapon-mounted condition.

When the participant encountered the pre-planned obstacle on one of his route legs, the experimenter instructed him as to which way to navigate around the obstacle. He then used his wayfinding system to navigate around the obstacle and back on to the route.

When the route navigation was complete, the experimenter saved the session's route file to disk and prepared for the next session. The participant completed NASA TLX workload questionnaires regarding the mission he just finished and the display type he just used.

At the completion of the experiment, all participants took part in a focus group and completed the exit questionnaire.

3.6 Measures

The following measures were collected during the experiment:

3.6.1 Objective Performance Data

The route taken by the participant was tracked by the FIND system and compared to the route plan to determine:

- Time to complete route: The total time in seconds the participant took to traverse the route.
- Extra distance travelled: The total distance travelled for each route was recorded by the FIND system. The actual route distance was then subtracted from this number to determine the extra distance travelled in metres.
- Root Mean Squared Error (RMSE) deviation: The extent of track deviation from the most direct route between waypoints was determined for each leg, using the RMSE and totalled for the route in metres.
- Accuracy of waypoint estimation: Participants were required to determine the location of each waypoint prior to initiating their next leg. The distance in metres from the actual waypoint location and the participant's estimated waypoint location were determined.
- Targets Engaged: The number of possible targets successfully engaged (out of 12 possible per route) was captured by the experimenter via remote control to the FIND system route file.

3.6.2 Subjective Questionnaire Data

At the completion of each wayfinding task, 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 discussions were held at the completion of the experiment. At the focus group, the participants completed an exit questionnaire where they rated the displays used according to the seven-point scale shown in Figure 10.

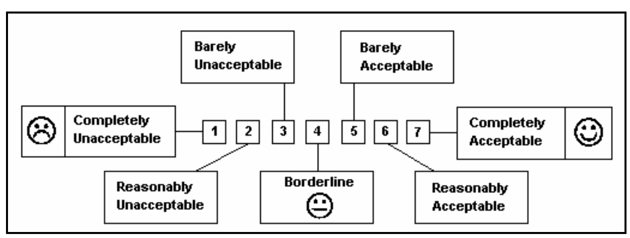


Figure 10: The Seven-Point Acceptability Scale

The exit questionnaire had participants rate items in the following categories:

- Effectiveness for Wayfinding
- Terrain Traverse
- Target Detection
- Usability
- Compatibility
- Display
- Overall Evaluation of the System

All questionnaires are provided in Annex A.

4. Statistical Analyses

A complete-block, repeated-measures design was used (see Table 2). Each of 16 participants navigated three routes, using a different display configuration for each. A repeated measures ANOVA and post hoc Duncan tests were performed for all objective performance data. A Friedman ANOVA was performed for all questionnaire data. Differences were identified at $p \leq 0.05$.

Table 2: Experimental Design

Display	Participating Subjects	Total Missions
1) Occluded Head Mounted Display	1 through 16	16
2) Heads-Up Display	1 through 16	16
2) Weapon-Mounted Display	1 through 16	16

5. Results

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

5.1 Participants

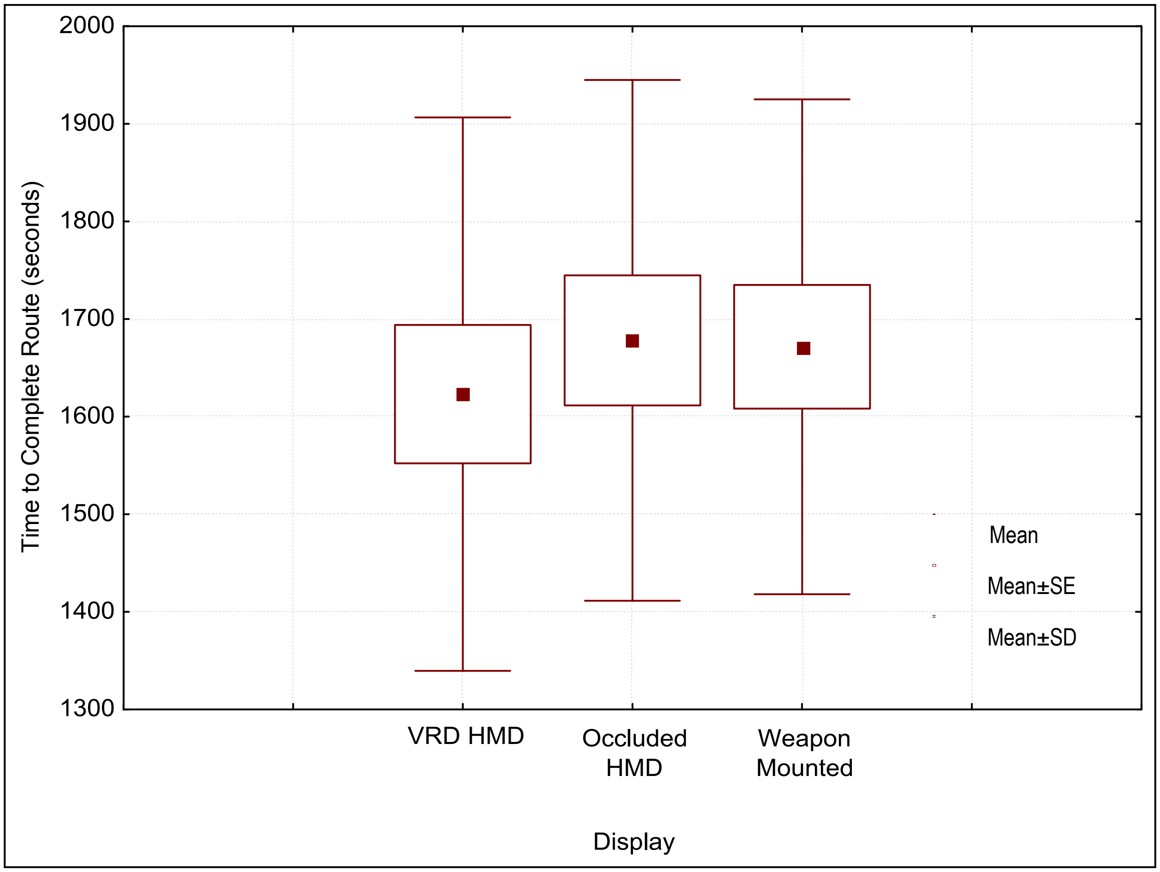
Sixteen regular force infantry soldiers from the 1st and 3rd battalions of the Princess Patricia Canadian Light Infantry (PPCLI) in Edmonton, Alberta participated in the field trial. There were 4 Privates, 11 Corporals or Master Corporals and 1 Sergeant. Their average number of years in service was 5 with a range of less than one year to more than 10 years of service.

5.2 Performance Results

The following sections present and discuss the mission performance results gathered using the FIND system.

5.2.1 Time to Complete Route

The time each participant took to complete his route (not including practice points), was recorded using the FIND system. The time for each route was subjected to a repeated measures analysis of variance with display type as the within-subjects effect. The results of this analysis and the mean and standard deviations are presented in Figure 11.



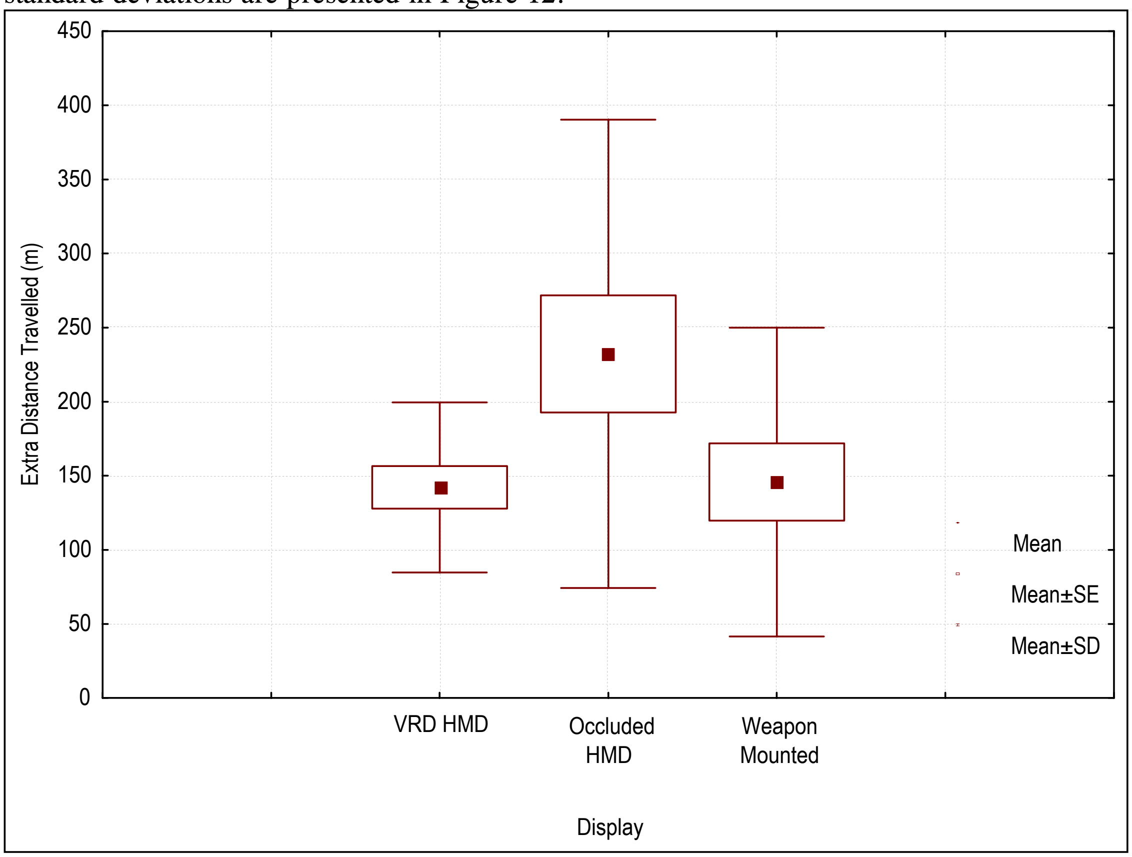
		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	F values and p values	Significant Differences
Time to Complete Route (s)	mean ± s.d.	1623 ± 284	1678 ± 267	1672 ± 253	F(2,30) = 0.225 p = 0.80018	None

Figure 11: Time to Complete Route

There were no significant differences between the display configurations for the time participants took to complete their wayfinding routes.

5.2.2 Extra Distance Travelled

Each wayfinding route used in the experiment was 1200 metres long. The total extra distance travelled by each participant as he navigated his route was collected using the FIND system. This distance was computed for each route and subjected to a repeated measures analysis of variance with display type as the within-subjects effect. The results of this analysis and the mean and standard deviations are presented in Figure 12.



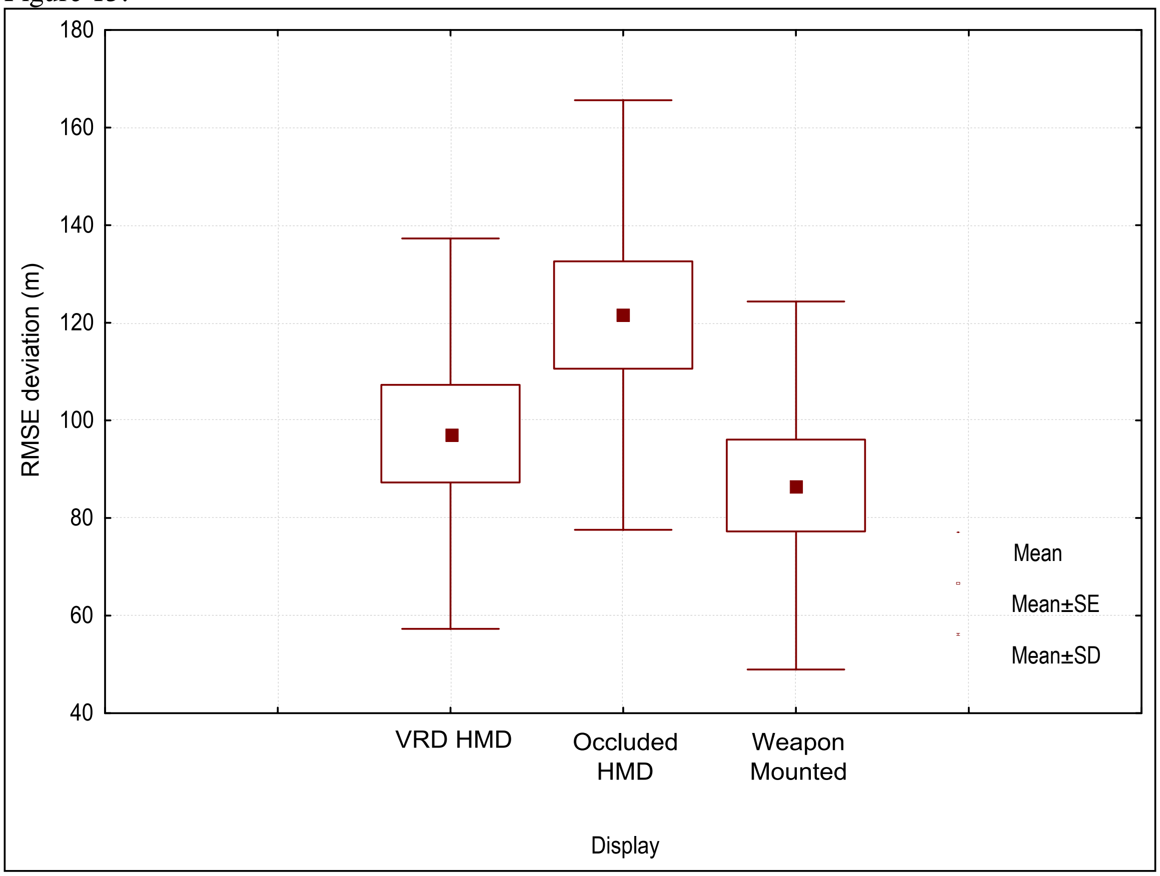
		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	F values and p values	Significant Differences
Extra Distance Travelled	mean ± s.d.	142 ± 57	232 ± 158	146 ± 104	F(2,30) = 3.6393 p = 0.03845	2>1,3

Figure 12: Extra Distance Travelled

The extra distance travelled when using the occluded display was significantly longer and more variable than with the other two displays.

5.2.3 Root Mean Square Error Deviation

The root mean square error (RMSE) deviation from the straight-line path was used as a measure of navigational accuracy. RMSE deviation was computed for each participant and subjected to a repeated measures analysis of variance with display type as the within-subjects effect. The results of this analysis and the RMSE deviation means and standard deviations are presented in Figure 13.



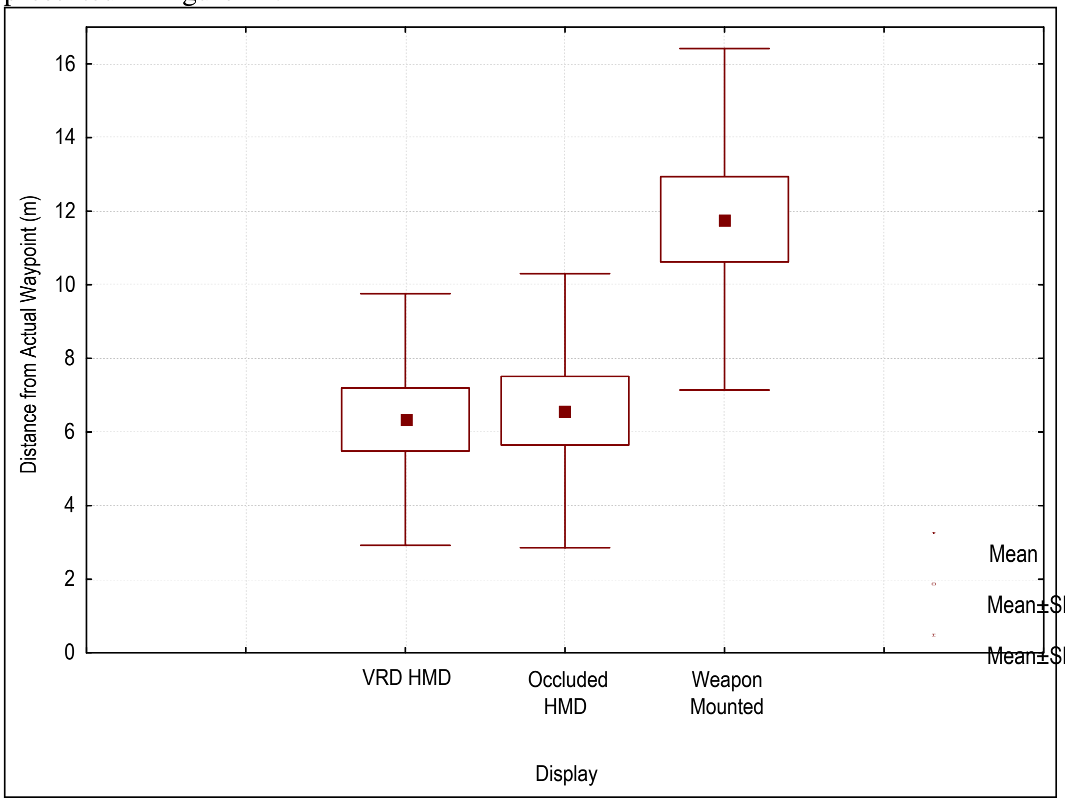
		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	F values and p values	Significant Differences
Root Mean Square Error (m)	mean ± s.d.	97 ± 40	122 ± 44	87 ± 37.7	F(2,30) = 3.2766 p = 0.035164	None

Figure 13: Root Mean Square Error Deviation

There were no significant differences between display types for RMSE deviation.

5.2.4 Accuracy of Waypoint Estimation

The accuracy of waypoint estimation was used as a measure of navigational accuracy. The offset distance between the actual waypoint location and the participant's estimation of the waypoint location was calculated for each route leg. The mean offset for the entire route was then calculated and subjected to a repeated measures analysis of variance with display type as the within-subjects effect. The results of this analysis and the means and standard deviations are presented in Figure 14.



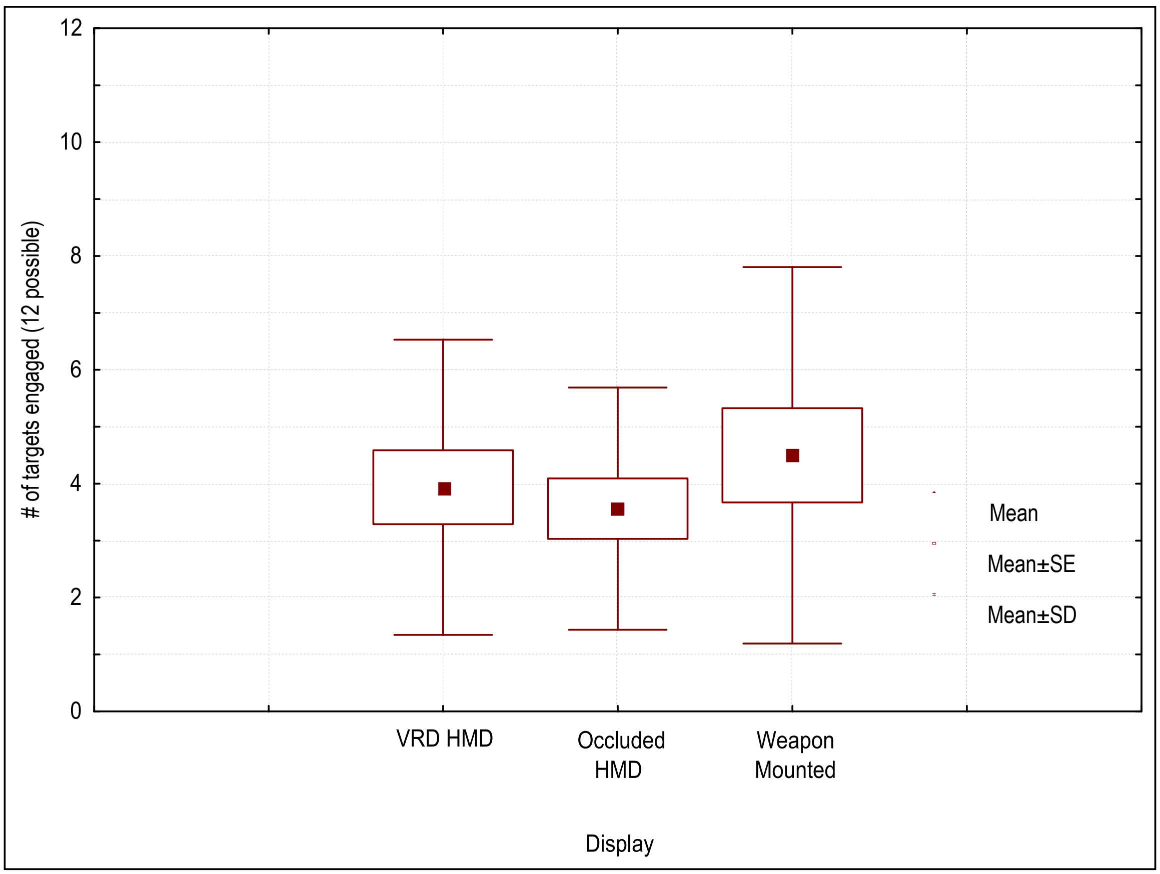
		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	F values and p values	Significant Differences
Distance from Actual Waypoint (m)	mean ± s.d.	6.0 ± 3.4	7.0 ± 3.7	12 ± 4.6	F(2,30) =11.580 p = 0.00019	3>1,2

Figure 14: Accuracy of Waypoint Estimation

Waypoint accuracy was significantly better with the two head-mounted displays when compared to the weapon-mounted display. However, the absolute distance in metres was small in operational terms.

5.2.5 Targets Engaged

There were twelve possible targets to engage on each wayfinding route. As a participant engaged targets enroute, the accompanying experimenter logged the target engagement on the FIND system file using a remote control. The number of targets engaged on each participant's route was subjected to a repeated measures analysis of variance with display type as the within-subjects effect. The results of this analysis and the means and standard deviations are presented in Figure 15.



		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	F values and p values	Significant Differences
# of Targets Engaged	mean ± s.d.	3.9 ± 2.6	3.6 ± 2.1	4.5 ± 3.3	F(2,30) =0.72766 p = 0.49137	None

Figure 15: Number of Targets Engaged

There were no significant differences in number of targets engaged according to display type.

5.3 Questionnaire Results

The following section presents results from the exit and NASA TLX workload questionnaires (See Annex A).

5.3.1 Effectiveness for Wayfinding

The exit questionnaire asked participants to rate each system's Effectiveness for Wayfinding according to nine criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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: Effectiveness for Wayfinding Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Reading the display while moving	mean ± s.d.	5.2 ± 1.3	4.1 ± 1.7	5.9 ± 0.7	$\chi2(16,2)=12.58$ $p < 0.00186$	1,3>2
	% unacceptable	18.8%	37.5%	0%		
Reading the display while stationary	mean ± s.d.	6.1 ± 0.9	5.7 ± 0.9	6.5 ± 0.5	$\chi2(16,2)=12.56$ $p < 0.00187$	3>1,2
	% unacceptable	0%	0%	0%		
Determining the direction of the waypoint	mean ± s.d.	5.6 ± 1.0	5.3 ± 1.1	6.3 ± 0.5	$\chi2(16,2)=16.71$ $p < 0.00024$	3>1,2
	% unacceptable	6.3%	6.3%	0%		
Determining the distance to the waypoint	mean ± s.d.	6.1 ± 1.3	6.1 ± 1.2	6.5 ± 0.5	$\chi2(16,2)=6.5$ $p < 0.03878$	None
	% unacceptable	6.3%	6.3%	0%		
Determining when the waypoint had been reached	mean ± s.d.	5.6 ± 1.4	5.6 ± 1.4	6.3 ± 0.6	$\chi2(16,2)=12.25$ $p < 0.00219$	3>1,2
	% unacceptable	6.3%	6.3%	0%		
Maintaining my pace while using the system	mean ± s.d.	5.6 ± 1.3	4.6 ± 1.8	6.0 ± 0.6	$\chi2(16,2)=8.88$ $p < 0.01178$	1,3>2
	% unacceptable	12.5%	31.3%	0%		
Maintaining my heading while using the system	mean ± s.d.	5.4 ± 1.4	4.4 ± 1.8	5.9 ± 0.7	$\chi2(16,2)=8.75$ $p < 0.01259$	1,3>2
	% unacceptable	12.5%	31.3%	0%		
Navigating back to the original route (after obstacles)	mean ± s.d.	5.6 ± 1.3	4.9 ± 1.3	6.1 ± 0.6	$\chi2(16,2)=15.20$ $p < 0.00050$	1,3>2
	% unacceptable	12.5%	18.8%	0%		
Overall effectiveness for wayfinding	mean ± s.d.	5.6 ± 1.0	4.6 ± 1.6	6.2 ± 0.5	$\chi2(16,2)=14.98$ $p < 0.00056$	1,3>2
	% unacceptable	6.3%	25.0%	0%		

The occluded display was rated unacceptable by more than 20% of participants in four Effectiveness for Wayfinding categories: "Reading the display while moving", "Maintaining my pace while using the system", "Maintaining my heading while using the system" and "Overall effectiveness for wayfinding". There were no categories where the other two systems were rated unacceptable by more than 20% of participants.

There were no significant differences between displays in the "determining the distance to the waypoint" category. In all other categories, the weapon-mounted display was rated significantly more acceptable than the occluded head-mounted display. Additionally, the weapon-mounted display was rated more acceptable than the VRD for "Reading the display while stationary", "Determining the direction of the waypoint" and "Determining when the waypoint had been reached". The weapon-mounted display was also rated more acceptable than the VRD for "Reading the display while moving", "Maintaining my pace while using the system", "Maintaining my heading while using the system", "Navigating back to the original route (after obstacles)" and "Overall effectiveness for wayfinding".

5.3.2 Terrain Traverse

The exit questionnaire asked participants to rate each system's acceptability for Terrain Traverse according to six criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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: Terrain Traverse Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Standing	mean ± s.d.	5.4 ± 1.2	5.1 ± 1.1	6.3 ± 0.6	$\chi 2(16,2)=14.97$ $p < 0.00056$	3>1,2
	% unacceptable	12.5%	6.3%	0%		
Kneeling	mean ± s.d.	5.2 ± 1.1	4.9 ± 1.0	5.8 ± 0.9	$\chi 2(16,2)=10.21$ $p < 0.00608$	3>1,2
	% unacceptable	12.5%	6.3%	0%		
Walking	mean ± s.d.	5.3 ± 1.3	3.7 ± 1.7	5.8 ± 0.7	$\chi 2(16,2)=18.63$ $p < 0.00009$	1,3>2
	% unacceptable	12.5%	43.8%	0%		
Detecting ground level hazards	mean ± s.d.	5.2 ± 1.0	3.9 ± 1.6	6.3 ± 0.5	$\chi 2(16,2)=25.12$ $p < 0.00000$	3>1,2 1>2
	% unacceptable	6.3%	37.5%	0%		
Detecting eye level hazards	mean ± s.d.	5.6 ± 0.9	3.7 ± 1.6	6.4 ± 0.5	$\chi 2(16,2)=25.27$ $p < 0.00000$	3>1,2 1>2
	% unacceptable	0%	56.3%	0%		
Navigating around hazards/ obstacles	mean ± s.d.	5.7 ± 0.8	4.7 ± 1.4	6.4 ± 0.5	$\chi 2(16,2)=21.81$ $p < 0.00002$	3>1,2 1>2
	% unacceptable	0%	31.3%	0%		
Overall ease of terrain traverse with system	mean ± s.d.	5.3 ± 0.9	4.1 ± 1.8	6.4 ± 0.5	$\chi 2(16,2)=18.90$ $p < 0.00008$	3>1,2 1>2
	% unacceptable	0%	43.8%	0%		

In the Terrain Traverse category, the occluded display was rated unacceptable by more than 20 percent of participants in five categories: "Walking", "Detecting ground level hazards", "Detecting eye level hazards", "Navigating around hazards/obstacles" and "Overall ease of terrain traverse with system". There were no categories where the other two systems were rated unacceptable by more than 20% of participants.

The weapon-mounted display was rated significantly more acceptable than the occluded head-mounted display for all Terrain Traverse categories. In addition, the weapon-display was rated significantly more acceptable than the VRD in every category except "Walking". Also, the VRD was rated significantly more acceptable than the occluded display in five categories: "Walking", "Detecting ground level hazards", "Detecting eye level hazards", "Navigating around hazards/obstacles" and "Overall ease of terrain traverse with system".

5.3.3 Target Detection

The exit questionnaire asked participants to rate each system's acceptability for Target Detection according to four criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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: Target Detection Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Searching for targets	mean ± s.d.	4.7 ± 1.4	3.5 ± 1.4	5.9 ± 1.0	$\chi^2(16,2)=24.15$	3>1,2
	% unacceptable	25.0%	56.3%	6.3%	$p < 0.00001$	1>2
Detecting targets	mean ± s.d.	4.6 ± 1.5	3.5 ± 1.6	5.9 ± 1.1	$\chi^2(16,2)=24.04$	3>1,2
	% unacceptable	25.0%	50.0%	6.3%	$p < 0.00001$	1>2
Engaging targets	mean ± s.d.	4.9 ± 1.4	3.7 ± 1.6	6.1 ± 0.8	$\chi^2(16,2)=21.92$	3>1,2
	% unacceptable	18.8%	43.8%	0%	$p < 0.00002$	1>2
Overall target detection and engagement	mean ± s.d.	4.6 ± 1.5	3.4 ± 1.5	6.1 ± 0.9	$\chi^2(16,2)=24.04$	3>1,2
	% unacceptable	25.0%	50.0%	0%	$p < 0.00001$	1>2

The occluded display was rated unacceptable by more than 20% of participants for all target detection questions. The VRD was rated unacceptable by more than 20% of participants for all but one target detection question, "Engaging Targets". There were no categories where the weapon-mounted display was rated unacceptable by more than 20% of participants.

In all target detection categories, the weapon-mounted display was rated significantly more acceptable than both head-mounted displays and the VRD was rated significantly more acceptable than the occluded display.

5.3.4 Usability

The exit questionnaire asked participants to rate each system's acceptability for Usability according to five criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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: Usability Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Ease of learning the system	mean ± s.d.	5.9 ± 0.7	5.8 ± 0.9	6.3 ± 0.7	$\chi^2(16,2)=7.76$ $p < 0.02065$	3>2
	% unacceptable	0%	0%	0%		
Ease of operating the system	mean ± s.d.	5.9 ± 1.0	5.8 ± 1.0	6.4 ± 0.7	$\chi^2(16,2)=7.28$ $p < 0.02625$	3>2
	% unacceptable	6.3%	6.3%	0%		
Adjustment for viewing display	mean ± s.d.	5.4 ± 1.5	4.6 ± 1.6	6.3 ± 0.7	$\chi^2(16,2)=17.59$ $p < 0.00015$	3>1,2
	% unacceptable	12.5%	25.0%	0%		
Ease of viewing local surroundings (with display in place)	mean ± s.d.	5.1 ± 1.1	3.8 ± 1.7	6.7 ± 0.5	$\chi^2(16,2)=24.79$ $p < 0.00000$	3>1,2 1>2
	% unacceptable	12.5%	43.8%	0%		
Overall usability	mean ± s.d.	5.4 ± 1.3	4.1 ± 1.7	6.5 ± 0.6	$\chi^2(16,2)=21.17$ $p < 0.00003$	3>1,2 1>2
	% unacceptable	12.5%	31.3%	0%		

In the usability category, the occluded display was rated unacceptable by more than 20% of participants in three categories: "Adjustment for viewing display", "Ease of viewing local surrounding (with display in place)" and "Overall usability". There were no categories where the other two systems were rated unacceptable by more than 20% of participants

The weapon-mounted display was rated significantly more acceptable than the occluded head-mounted display in all usability categories. Additionally, in the "Adjustment for viewing", "Ease of viewing local surroundings (with display in place)" and "Overall Usability" category, the weapon-mounted display was rated significantly more acceptable than the VRD. Also in "Ease of viewing local surroundings (with display in place)" and "Overall usability", the VRD was rated significantly more acceptable than the occluded display.

5.3.5 Compatibility

The exit questionnaire asked participants to rate each system's acceptability for Compatibility according to four criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. Mean ratings and standard deviations were computed for each condition, and a Friedman's analysis of variance was conducted. The results are summarized in Table7. 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: Compatibility Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Compatibility (interference) with clothing	mean ± s.d.	5.3 ± 0.9	5.3 ± 0.9	6.6 ± 0.5	$\chi^2(16,2)=22.17$ $p < 0.00002$	3>1,2
	% unacceptable	6.3%	6.3%	0%		
Compatibility (interference) with weapon	mean ± s.d.	5.4 ± 1.0	5.1 ± 1.1	6.3 ± 1.1	$\chi^2(16,2)=16.93$ $p < 0.00021$	3>1,2
	% unacceptable	6.3%	12.5%	6.3%		
Compatibility (interference) with equipment	mean ± s.d.	5.3 ± 1.0	5.3 ± 0.9	6.4 ± 0.7	$\chi^2(16,2)=22.15$ $p < 0.00002$	3>1,2
	% unacceptable	6.3%	6.3%	0%		
Overall compatibility rating	mean ± s.d.	5.3 ± 1.1	5.1 ± 1.0	6.3 ± 0.9	$\chi^2(16,2)=16.51$ $p < 0.00026$	3>1,2
	% unacceptable	6.3%	6.3%	0%		

For all three displays, there were no items in the compatibility section where more than 20% of participants rated the display as unacceptable.

In all compatibility categories, the weapon-mounted display was rated significantly more acceptable than the two head-mounted displays.

5.3.6 Display

The exit questionnaire asked participants to rate each system's Display according to eight criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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 8. 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 8: Exit Questionnaire: Display Results

		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Ease of viewing display image	mean ± s.d.	5.5 ± 1.5	1.7 ± 0.7	6.4 ± 0.5	$\chi^2(16,2)=15.62$ $p < 0.00041$	3>1,2
	% unacceptable	12.5%	25.0%	0%		
Quality of image detail	mean ± s.d.	6.0 ± 0.6	5.7 ± 0.7	6.4 ± 0.5	$\chi^2(16,2)=11.21$ $p < 0.00367$	3>1,2
	% unacceptable	0%	0%	0%		
Quality of image colour	mean ± s.d.	5.8 ± 0.8	5.6 ± 0.6	6.3 ± 0.4	$\chi^2(16,2)=10.75$ $p < 0.00463$	3>1,2
	% unacceptable	0%	0%	0%		
Image stability	mean ± s.d.	4.9 ± 1.7	4.6 ± 2.0	6.4 ± 0.5	$\chi^2(16,2)=15.80$ $p < 0.00037$	3>1,2
	% unacceptable	25.0%	31.3%	0%		
Viewing in bright lighting conditions	mean ± s.d.	4.3 ± 2.0	4.6 ± 1.4	6.3 ± 1.1	$\chi^2(16,2)=14.09$ $p < 0.00087$	3>1,2
	% unacceptable	31.3%	25.0%	6.3%		
Viewing in dim lighting conditions	mean ± s.d.	5.6 ± 1.3	5.4 ± 1.0	6.2 ± 0.7	$\chi^2(16,2)=11.09$ $p < 0.00391$	3>1,2
	% unacceptable	12.5%	6.3%	0%		
Display glare	mean ± s.d.	5.2 ± 1.5	5.1 ± 1.2	5.7 ± 1.2	$\chi^2(16,2)=7.80$ $p < 0.02024$	None
	% unacceptable	18.8%	12.5%	6.3%		
Overall display quality	mean ± s.d.	5.4 ± 1.1	5.3 ± 1.0	6.3 ± 0.5	$\chi^2(16,2)=15.95$ $p < 0.00034$	3>1,2
	% unacceptable	6.3%	6.3%	0%		

In the Display category, both the occluded display and the VRD were rated unacceptable by more than 20% of participants for "Image stability" and "Viewing in bright lighting conditions". Additionally, the occluded display was rated unacceptable by more than 20% of respondents for "Ease of viewing display image". There were no items where the weapon-mounted display was rated unacceptable by more than 20% of respondents.

In all categories, except "Display glare", the weapon-mounted display was rated significantly more acceptable than both head-mounted displays. There were no significant differences in the "Display glare" category.

5.3.7 Overall Evaluation of the System

The exit questionnaire asked participants to rate each system's Overall Acceptability according to six criteria. Participants rated the criteria using the seven-point acceptance scale in Figure 10. 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 9. 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 9: Exit Questionnaire: Overall Evaluation of the System Results

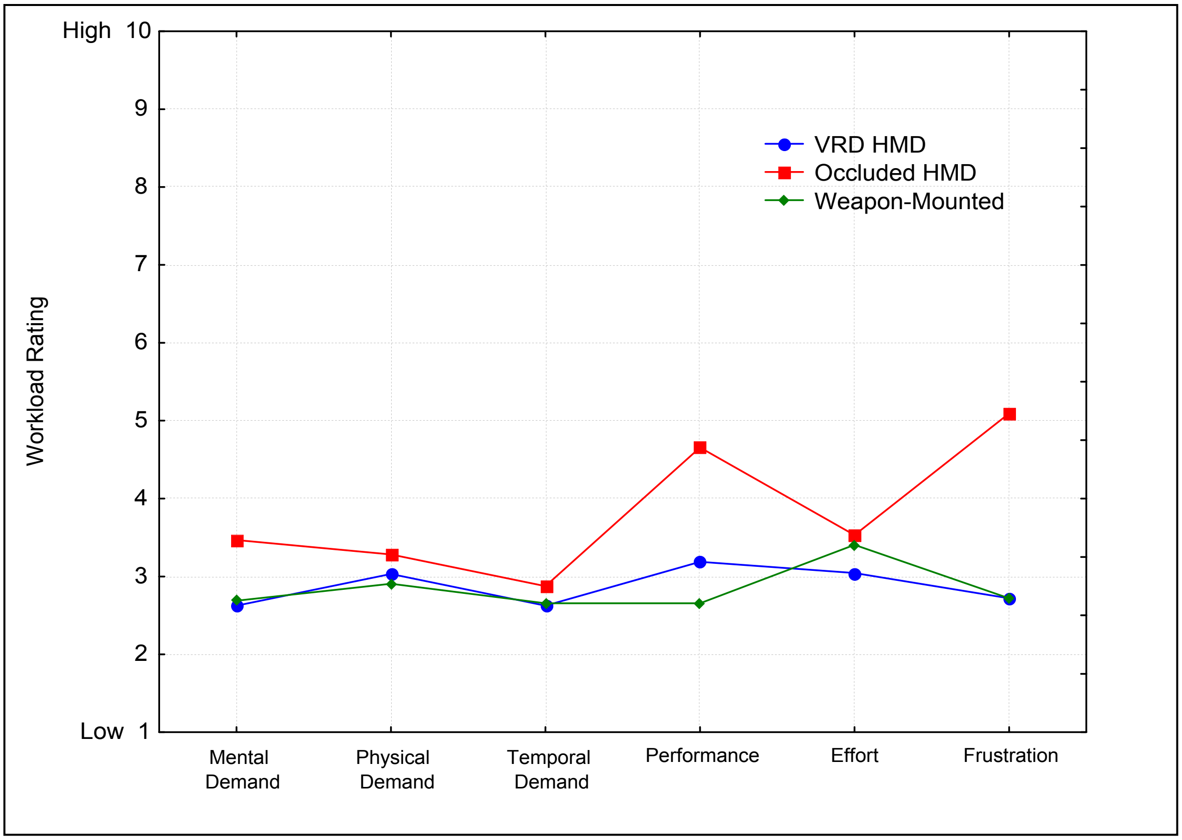
		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Confidence in the system	mean ± s.d.	5.1 ± 1.7	4.7 ± 1.7	6.3 ± 0.8	$\chi^2(16,2)=18.67$ $p < 0.00009$	3>1,2
	% unacceptable	18.8%	18.8%	0%		
Mental workload	mean ± s.d.	5.8 ± 1.1	5.3 ± 1.6	6.1 ± 1.2	$\chi^2(16,2)=6.35$ $p < 0.04184$	3>2
	% unacceptable	6.3%	12.5%	6.3%		
Tactical feasibility	mean ± s.d.	4.6 ± 1.7	3.8 ± 2.1	6.4 ± 0.5	$\chi^2(16,2)=23.29$ $p < 0.00001$	3>1,2
	% unacceptable	12.5%	31.3%	0%		
Accuracy of the system	mean ± s.d.	5.3 ± 1.7	5.1 ± 1.7	6.4 ± 0.8	$\chi^2(16,2)=14.97$ $p < 0.00056$	3>1,2
	% unacceptable	12.5%	12.5%	0%		
Durability of the system	mean ± s.d.	3.6 ± 1.5	3.6 ± 1.7	6.3 ± 0.8	$\chi^2(16,2)=24.37$ $p < 0.00001$	3>1,2
	% unacceptable	31.3%	25.0%	0%		
Overall acceptability of the system	mean ± s.d.	4.9 ± 1.6	4.1 ± 1.8	6.4 ± 0.5	$\chi^2(16,2)=24.50$ $p < 0.00000$	3>1,2
	% unacceptable	18.8%	31.3%	0%		

Both head-mounted displays were rated unacceptable by more than 20% of participants for "Durability of the system". In addition, the occluded display was rated unacceptable by more than 20% of participants for "Tactical feasibility" and "Overall acceptability of the system". There were no categories where the weapon-mounted display was rated unacceptable by more than 20% of participants.

In all categories except "Mental workload", the weapon-mounted display was rated more acceptable than the two head-mounted displays. In the "Mental workload" category, the weapon-mounted display was rated significantly more acceptable than the occluded head-mounted display only.

5.3.8 Workload Questionnaire

After completing the wayfinding and target detection task with each system, 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 a Friedman's analysis of variance was conducted. The results are summarized in Figure 16.



		1. VRD HMD	2. Occluded HMD	3. Weapon Mounted	Chi Squared and p values	Significant Differences
Mental Demand	mean ± s.d.	2.6 ± 1.5	3.5 ± 2.1	2.7 ± 1.4	$\chi^2(16,2)=4.04$ $p < 0.13285$	None
Physical Demand	mean ± s.d.	3.0 ± 1.7	3.3 ± 1.6	2.9 ± 1.8	$\chi^2(16,2)=2.04$ $p < 0.36074$	None
Temporal Demand	mean ± s.d.	2.6 ± 1.5	2.9 ± 1.6	2.7 ± 1.4	$\chi^2(16,2)=0.50$ $p < 0.77880$	None
Performance	mean ± s.d.	3.2 ± 1.9	4.7 ± 2.7	2.7 ± 1.3	$\chi^2(16,2)=3.93$ $p < 0.14017$	None
Effort	mean ± s.d.	3.0 ± 1.6	3.5 ± 2.2	3.4 ± 2.1	$\chi^2(16,2)=1.02$ $p < 0.60104$	None
Frustration	mean ± s.d.	2.7 ± 1.4	5.1 ± 2.6	2.7 ± 1.3	$\chi^2(16,2)=9.75$ $p < 0.00764$	2>1,3

Figure 16: NASA TLX Workload Results

An analysis of variance indicated Frustration to be the only component of workload where there were significant differences between the three conditions. The occluded display was rated significantly more frustrating than the other two displays.

5.4 Focus Group

A focus group was held at the conclusion of the experiment with all sixteen subjects participating. The discussion was organized according to the categories used on the exit questionnaire.

5.4.1 Wayfinding

For wayfinding, participants commented that all three systems worked well and no one system was more difficult than the other to use. The occluded display gave some participants the sense they veered off course to the left because they walked in the direction of the open eye. Overall they felt that a handheld GPS was all that a soldier required for navigation.

5.4.2 Terrain Traverse

For terrain traverse, the participants agreed that the weapon-mounted display was the most preferable. The commented that the occluded display was the worst for terrain traverse, because they found it cut off their view of the ground and left them vulnerable to tripping hazards. They commented that this was less of a problem with the VRD.

5.4.3 Target Detection

Participants felt that of the three displays tested, target detection was most difficult with the occluded display because it blocked the soldier's line of sight. They felt that the VRD was easier to use for target detection than the occluded display, but the weapon-mounted display was optimal for target detection. Participants commented that with all displays they felt they missed more targets while walking than while standing still.

5.4.4 Usability

In terms of usability participants felt that there was little difference between the three systems. However they did comment that both the head-mounted displays were sometimes difficult to align to the eye. The occluded display tended to bounce around when walking, forcing the user to stop and re-align the display in order to view it. Both HMDs could be easily bumped by branches and knocked out of alignment. However, if they were properly aligned, participants felt they were quicker to use than the weapon-mounted display.

5.4.5 Compatibility

Participants were generally concerned with compatibility with the helmet for the HMDs. They expressed concern that so much equipment (e.g. radio headsets, microphones, NVGs) is being added to the helmet and it may not all be compatible. They felt that the weapon-mounted display was the most compatible because it was small and not worn on the head. They felt that the wayfinding system should be combined with other head-mounted equipment to reduce compatibility issues and limit the weight of equipment on the head. For the weapon-mounted display, participants commented that there should be an option to remove it from the rifle and use it as a handheld GPS system.

5.4.6 Display

Participants felt that the occluded display was the worst in terms of display quality. They found it put stress on the eye and caused headaches. However, they found that the VRD display was difficult to see in sunny conditions, because the display was washed out by the bright light.

5.4.7 Overall

At the end of the focus group, participants were asked to vote for which of the three systems they preferred overall. The results are shown in Table 10.

Table 10: Focus Group Vote: Overall Preference

	VRD HMD	Occluded HMD	Weapon Mounted
Focus Group Vote: Overall Preference	1	0	15

Participants commented that a hand-held commercial GPS would be the most preferable system. They commented that the HMDs were "before their time" and too expensive to be practical.

They also commented that the incorporation of wayfinding systems and digital maps would require changes in the way the infantry works, the processes they use and other equipment and tools. They couldn't be introduced effectively without these cultural and procedural changes.

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 11 summarizes the major results of this experiment:

Table 11: Summary of Major Results

	Measure	Significant Differences
Mission Performance Results	**Time to Complete Route**	None
	Extra Distance Travelled	Occluded > VRD, Weapon Mount
	Root Mean Squared Error Deviation	None
	Waypoint Estimation Error	Weapon Mount > VRD, Occluded
	Targets Engaged	None
Exit Questionnaire Results	**Overall Effectiveness for Wayfinding**	Weapon Mount, VRD > Occluded
	Overall Ease of Terrain Traverse with System	Weapon Mount > VRD, Occluded VRD > Occluded
	Overall Target Detection and Engagement	Weapon Mount > VRD, Occluded VRD > Occluded
	Overall Usability	Weapon Mount > VRD, Occluded VRD > Occluded
	Overall Compatibility	Weapon Mount > VRD, Occluded
	Overall Display Quality	Weapon Mount > VRD, Occluded
	Overall Acceptability of the System	Weapon Mount > VRD, Occluded

Table 11: Summary of Major Results (Cont.)

	Measure	Significant Differences
NASA TLX workload questionnaire results	**Mental Demand**	None
	Physical Demand	None
	Temporal Demand	None
	Performance	None
	Effort	None
	Frustration	Occluded > Weapon Mount, VRD

For mission performance, significant differences occurred in only two categories, Extra Distance Travelled and Waypoint Estimation Error. For Extra Distance Travelled, participants travelled a significantly longer distance with the occluded display as compared to the other two displays. Participants in the focus group felt they had veered off course in the direction of their unobstructed eye when using the occluded display. This may account for the extra distance travelled while using this display.

For Waypoint Estimation Error, the error with the weapon-mounted display was significantly more than with the two head-mounted displays. This may be attributable to the difference in the position of the GPS receiver between these conditions. In the head-mounted conditions, the GPS receiver was on a platform attached to top of the FIND system, just above the participant's shoulder. In the weapon-mounted condition, the GPS receiver was also weapon-mounted, and thus may have had poorer access to satellites as the participant moved or lowered his weapon or possibly shielded the receiver with his body while navigating. Using a head-mounted GPS receiver, and a weapon-mounted display only, may reduce this error. The mean waypoint accuracy error with all three displays was less than 20 metres, which is acceptable for infantry applications.

Questionnaire results often differed significantly from the performance results. Table 12 presents a summary of exit questionnaire items where more than 20% of participants rated a system unacceptable according to the seven-point scale in Figure 10.

Table 12: Exit Questionnaire Items with less than 80% Acceptability

Display	Questionnaire Category	Questionnaire Items with less than 80% Acceptability
Weapon-Mounted Display	None	None
Occluded Display	Effectiveness for Wayfinding	Reading the display while moving
		Maintaining my pace while using the system
		Maintaining my heading while using the system
		Overall effectiveness for wayfinding
	Terrain Traverse	Walking
		Detecting ground level hazards
		Detecting eye level hazards
		Navigating around hazards/obstacles
		Overall ease of terrain traverse with system
	Target Detection	Searching for targets
		Detecting targets
		Engaging targets
		Overall target detection and engagement
	Usability	Adjustment for viewing display
		Ease of viewing local surrounding (with display in place)
	Display	Ease of viewing display image
		Image stability
		Viewing in bright light conditions
	Overall Evaluation of the System	Tactical feasibility
		Durability of the system
		Overall acceptability of the system
Virtual Retinal Display	Target Detection	Searching for targets
		Detecting targets
		Engaging targets
		Overall target detection and engagement
	Display	Image stability
		Viewing in bright light conditions
	Overall Evaluation of the System	Durability of the system

Although the occluded display was rated unacceptable by more than 20% of participants for four "Effectiveness for Wayfinding" questionnaire items, wayfinding performance while using the occluded display was significantly worse than with the other two systems for "Extra Distance Travelled" only. Additionally, "Waypoint Estimation Error" was significantly worse with the weapon-mounted display than with the other two displays, however participants seemed unaware of the small but significant difference as there were no items at all where the weapon-mounted system was rated unacceptable by more than 20% of participants.

Target detection is another area where performance results and questionnaire results differed. While questionnaire and focus group results indicated that participants felt their target detection and engagement performance was superior with the weapon-mounted display as compared to the two head-mounted displays, there were no significant differences between the systems for target engagement performance. This may suggest that soldiers are aware of any loss in their field of vision and are concerned about any reduction in visual situation awareness.

The significantly higher frustration rating for the occluded display on the workload questionnaire, could explain its poor performance overall on the exit questionnaire. Participants may have been so frustrated by the display in general that they tended to rate it more harshly in many questionnaire categories.

6.2 Recommendations

This section presents recommendations for improvements specific to the display types used in this experiment.

6.2.1 Weapon-mounted displays

Questionnaire results indicated that the weapon-mounted display was the preferred format for visual wayfinding information. If a weapon-mounted display is issued for infantry use certain improvements are recommended. The GPS receiver for a weapon-mounted display (or any other display) should be mounted on the helmet and not with the display on the weapon. As a participant navigates his route, his weapon may move to various positions that may obscure a weapon-mounted GPS receiver from GPS satellite signals. Also, any weapon-mounted display should be easily removable from the weapon, so that it can be handheld or switched to another weapon as needed.

6.2.2 Head mounted displays

Although the results indicated that a weapon-mounted display was the preferred format for visual wayfinding information, there are some soldiering situations where a helmet-mounted display may be more appropriate. Also, soldiers may already wear helmet-mounted displays for other reasons and these displays may be easily adaptable to included wayfinding information. Thus it is recommended to continue research on helmet-mounted displays. Of the two head-mounted displays, questionnaire results indicated a strong preference for the VRD display over the occluded display. Workload questionnaire results also indicated a higher level of frustration with the occluded system and performance results showed that participants travelled longer distances when using the occluded display.

While questionnaire results indicated some difficulty with using the VRD display in terms of image stability, viewing in bright lighting conditions, durability and target detection, performance results in target engagement indicated no significant differences between any of the systems. The VRD also performed as well or better than the other two systems for all mission performance tasks. It is therefore recommended that future work with helmet-mounted displays use the VRD or other see-through designs, as opposed to an occluded display.

The soldiers who participated in this study were very concerned about the impact of extra gadgets and weight being attached to the helmet. For this reason, any helmet-mounted display for wayfinding information should be incorporated into other head-mounted systems (for example night vision goggles, or radio communications systems), and not add to the overall weight of the helmet. Should a VRD be issued for regular military use, improvements in durability, image stability and viewing in bright light conditions are required.

Ideally, any wayfinding display system should be adaptable to a variety of formats (e.g. weapon-mounted, head-mounted, helmet-mounted, handheld) so soldiers have a choice of display format depending on the situation.

6.3 Further Work

The results of this research indicate various lines of further work for soldier modernization projects. Recommendations for areas of future study are presented in this section.

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. A wayfinding system should be integrated so that it is combined with (or at the very 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.

6.3.2 Weight of Helmet Mounted Systems

Soldiers in this study were very concerned about the weight of systems being added to their helmets. Studies should be conducted to determine how much weight can be worn and how it should be best distributed on the head of an infantry soldier without causing injury or compromising performance in soldiering tasks.

6.3.3 Other Visual Displays

This research investigated only three types of visual displays. Other methods of displaying visual information to the eye should be investigated to evaluate their suitability for infantry applications. Some of these displays include:

- Arm or wrist mounted displays
- Flip-down tablet displays that are mounted to a soldier's shirt or tactical vest.
- See-through prism displays that sit off the eye and thus do not occlude the eye to the same degree as the M1 display used in this study, but may be more effective in bright sunlight than the VRD display.

6.3.4 Non-Wayfinding Visual information

The information presented in the visual displays used in this study provided wayfinding information only. Soldiers require many other types on information to perform their tasks, and some of this information may be appropriately provided on a visual display. For example, small changes to a wayfinding display would allow it to be used as an augmented reality tool. The system could provide information on the distance and bearing to other features on the battlefield in addition to route waypoints. For example information on enemy and friendly force locations, known obstacles and RV points could be displayed to the soldier on visual displays. An investigation of visual displays presenting this type of information is recommended.

6.3.5 Real-time Information Updating

In this experiment, route information was pre-programmed into the FIND system for display to the participant. In reality, routes can change once a mission has begun if new intelligence is received. The route information should be easily updateable by the soldiers wearing the system, or remotely by a commanding officer. Other information, such as the location of moving friendly forces could be updated real-time with the use of GPS receivers. Further research for this application is recommended.

7. References

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ANNEX A:
Questionnaires

Workload NASA TLX QUESTIONNAIRE

PARTICIPANT ID# : ________

RUN #: 1 ☐ 2 ☐ 3 ☐ **ROUTE #:** 1 ☐ 2 ☐ 3 ☐

CONDITION: **NOMAD VRD** ☐ **M1 HMD** ☐ **Weapon Mount** ☐

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?)

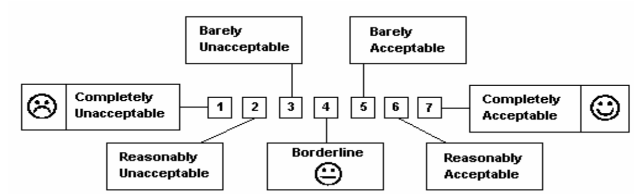
Low — **High**

FRUSTRATION

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

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

EXIT QUESTIONNAIRE



Participant ID#: ______________ **DATE:_________________**

	NOMAD VRD	M1 HMD	WEAPON MOUNT
EFFECTIVENESS FOR WAYFINDING	**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
Reading the display while moving	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Reading the display while stationary	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Determining the direction of the waypoint	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Determining the distance to the waypoint	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Determining when the waypoint had been reached	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Maintaining my pace while using the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Maintaining my heading while using the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Navigating back to the original route (after obstacles)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Effectiveness For Wayfinding	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

EXIT QUESTIONNAIRE

	NOMAD VRD							M1 HMD							WEAPON MOUNT						
	Acceptance Rating							Acceptance Rating							Acceptance Rating						
TERRAIN TRAVERSE	☹ 1	2	3	😐 4	5	6	☺ 7	☹ 1	2	3	😐 4	5	6	☺ 7	☹ 1	2	3	😐 4	5	6	☺ 7
Standing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kneeling (if applicable)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Walking	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Detecting ground level hazards	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Detecting eye level hazards	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Navigating around hazards / obstacles	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Overall Ease Of Terrain Traverse With System	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
TARGET DETECTION																					
Searching for targets	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Detecting targets	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Engaging targets	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Overall Target Detection & Engagement	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

EXIT QUESTIONNAIRE

	NOMAD VRD	M1 HMD	WEAPON MOUNT
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
Ease of learning the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of operating the system	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Adjustment for Viewing Display	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of Viewing Local Surroundings (with Display in place)	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Usability	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
COMPATIBILITY			
Compatibility (interference) with clothing	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility (interference) with weapon	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Compatibility (interference) with equipment	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Overall Compatibility Rating	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

EXIT QUESTIONNAIRE

	NOMAD VRD							M1 HMD							WEAPON MOUNT						
DISPLAY	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
Ease of Viewing Display Image	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Quality of Image Detail	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Quality of Image Colour	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Image Stability	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Viewing in Bright Lighting Conditions	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Viewing in Dim Lighting Conditions	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Display Glare	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Overall Display Quality	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
OVERALL																					
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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Examination of Head−Mounted, Heads−Up and Weapon−Mounted Visual Displays for Infantry Soldiers (U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

Heather J. Colbert; David W. Tack; Jeffery C. Bos

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
May 2005	60	5

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(U) This experiment built on previous SIREQ−TD studies by quantifying the performance and utility of head−mounted, heads−up and weapon−mounted visual displays during a wayfinding and target detection task. A four−day field trial took place at Ft. Benning, Georgia with sixteen regular force infantry soldiers participating. Participant soldiers navigated 1200−metre routes through wooded terrain using an enhanced wayfinding aid in each of three display conditions. As a secondary task, participants were required to detect and engage targets on their route. Three configurations for an enhanced wayfinding aid were investigated: 1) A head−mounted occluded display featuring a wayfinding display generated by the Future Infantry Navigation Device (FIND) system. 2) A head−mounted non−occluded virtual retinal display featuring a wayfinding display generated by the FIND system. 3) A weapon mounted Garmin e−trex GPS on the "Navigate" page and showing the "Big Compass" display.

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 strongly preferred by the participants.

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; Head mounted visual display; heads−up visual display; weapon−mounted visual display; visual display; FIND; Future Infantry Navigation Device; GPS; Garmin e−trex; wayfinding; target detection