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ALTERNATIVE METHODS FOR PROVIDING SURVEY AND ROUTE INFORMATION DURING OPEN COUNTRY TERRAIN NAVIGATION

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Abstract

There has been little research comparing the utility and usability of digital map models and digital wayfinding aids to other traditional terrain navigation tools for small-scale navigation at the small unit and individual soldier level. For this reason, this experiment investigated two visualization methods that contribute mostly to survey knowledge (i.e. digital versus paper map information) and two wayfinding methods that contribute mostly to route knowledge (i.e. digital wayfinding system versus compass). This experiment compared three combinations of survey and route knowledge support: a digital map with a directional icon displayed on a head-mounted display (HMD), a digital map displayed on a tablet with a digital audio wayfinding aid (Future Infantry Navigating Device or FIND), and a paper topographic map with a compass.

Results indicated the digital map displayed on a tablet with a digital audio wayfinding aid (FIND) was most frequently the highest rated modality across the questionnaires, and produced the best performance outcomes. The FIND modality attained significantly higher ratings than the paper map for awareness of own location, awareness of waypoint locations, ability to find the next waypoint after avoiding a hazard, determining when a waypoint has been reached, and was found to be very accurate for navigation purposes. The FIND modality was rated significantly more acceptable than the paper map and compass for ease of navigating a route, and generated superior performance for minimizing track deviation from the assigned route. The FIND modality also attained significantly higher ratings than the digital map alone (HMD) for determining direction to waypoint.

These results support the use of a digital map tablet for small unit commanders for use during route planning, mission briefings, and battlefield awareness during mission execution. A digital wayfinding aid (e.g. FIND) is supported for the rifleman tasked with the role of navigator or wayfinder, where the emphasis is reaching planned waypoints accurately while still making the best tactical use of the immediate ground and observing arcs for possible enemy forces.

Several important issues were identified with the use of digital maps that can affect their utility in the field. These issues are discussed and future research issues are described.

Résumé

Peu de recherches ont été effectuées pour comparer l'utilité et la facilité d'utilisation des modèles de cartes numériques et des aides numériques à l'orientation avec d'autres outils classiques de navigation sur le terrain, pour la navigation à petite échelle et au niveau des petites unités et des soldats. Pour cette raison, cette expérience visait à étudier deux méthodes de visualisation qui contribuent principalement à la reconnaissance du terrain (soit une visualisation numérique par rapport aux cartes imprimées) et deux méthodes d'orientation qui contribuent principalement à la connaissance de la route (soit un système d'orientation numérique par rapport à la boussole). Cette expérience comparait trois combinaisons d'outils de reconnaissance du terrain et de repérage de la route : une carte numérique avec une icône de direction à affichage sur visiocasque; une carte numérique à affichage sur tablette graphique avec un appareil audionumérique d'orientation (*Future Infantry Navigating Device* ou *FIND*); une carte topographique sur papier avec une boussole.

D'après les résultats, on a constaté que la carte numérique à affichage sur tablette graphique avec l'appareil audionumérique d'orientation (FIND) obtenaient plus fréquemment la meilleure cote dans l'ensemble des questionnaires et ont permis d'exécuter les meilleures performances. Le classement de la méthode FIND était beaucoup plus élevé que la carte imprimée en ce qui a trait à la position du participant lui-même, à la position des points de cheminement, à la capacité de trouver le point de cheminement suivant après avoir contourné un secteur dangereux et à la possibilité de déterminer si le point de cheminement était atteint. En outre, cette méthode a démontré une grande exactitude aux fins de la navigation. Ainsi, la méthode FIND a été jugée beaucoup plus acceptable que la carte imprimée et la boussole en ce qui concerne la facilité de suivre un itinéraire et a donné lieu à une performance supérieure en permettant de réduire les écarts de la route prévue. En outre, la méthode FIND a obtenu des cotes beaucoup plus élevées que la carte numérique seule (visiocasque) pour ce qui est de déterminer la direction vers le point de cheminement.

De tels résultats soutiennent l'utilisation d'une tablette graphique pour l'affichage d'une carte numérique à des fins de planification de routes, de séances d'information sur les missions et de reconnaissance du champ de bataille pendant l'exécution d'une mission. L'utilisation d'une aide numérique à l'orientation (par ex. FIND) est souhaitable dans le cas d'un carabinier chargé de la navigation ou de l'orientation, dont la responsabilité consiste principalement à atteindre exactement les points de cheminement prévus tout en faisant le meilleur usage tactique du milieu environnant et des arcs d'observation pour éventuellement repérer les forces ennemies.

En ce qui concerne l'utilisation de cartes numériques, on a identifié plusieurs problèmes importants qui peuvent influencer leur utilité sur le terrain. Ces problèmes seront abordés dans le présent rapport, de même que les enjeux de futures recherches.

Executive Summary

To support various navigation tasks (e.g. route planning, mission briefing, terrain awareness, wayfinding, battlefield awareness), navigation information can be provided in two basic forms: route knowledge and survey knowledge. Route knowledge refers to information about a particular path in the terrain whereas survey knowledge refers to information about the larger terrain space with the associated route included (e.g. a map). While route knowledge information is less voluminous than survey knowledge information, it also tends to be less adaptable to the likely need for changes during an infantry mission.

There has been little research comparing the utility and usability of digital map models and digital wayfinding aids to other traditional terrain navigation tools for small-scale navigation at the small unit and individual soldier level. For this reason, this experiment investigated two visualization methods that contribute mostly to survey knowledge (i.e. digital versus paper map information) and two wayfinding methods that contribute mostly to route knowledge (i.e. digital wayfinding system versus compass). This experiment compared three combinations of survey and route knowledge support: a digital map with a directional icon displayed on a head-mounted display (HMD), a digital map displayed on a tablet with a digital audio wayfinding aid (Future Infantry Navigating Device or FIND), and a paper topographic map with a compass.

Results indicated the digital map displayed on a tablet with a digital audio wayfinding aid (FIND) was most frequently the highest rated modality across the questionnaires and performance measures. The FIND modality attained significantly higher ratings than the paper map on the Exit Questionnaire for overall acceptability of method. Soldiers stated that the FIND modality was very accurate for navigation purposes and that it was easy to maintain the correct heading while using the system. This modality was rated significantly more acceptable than the paper map and compass for ease of navigating route. The FIND modality performed significantly better than the compass modality on performance measures for mean track deviation from the assigned route. The FIND modality attained significantly higher ratings than the digital map alone for determining direction to waypoint.

Despite being strongly supported by questionnaire and performance results for navigation, several problems were identified with the FIND modality with regard to terrain visualization and route planning. With regard to route planning, the FIND modality was uniquely rated acceptable by less than 80% of soldiers on the Pre-Mission Questionnaire for route planning, completeness of terrain knowledge, and ease of interpreting information. Due to technological problems, the digital map did not always accurately update and show their correct location.

In general, the digital map alone with the directional icon (HMD display) was rated superior to the paper map but was not rated as highly as the tablet digital map with audio wayfinding aid. The only item for which the digital map alone was rated more acceptable than the tablet digital map with audio wayfinding aid was ease of estimating distance. This rating for ease of estimating distances on the map was supported by the performance measures for error estimating bearing to mission objectives where the FIND and HMD modalities were significantly more accurate than the paper map with compass modality. However, this tool did not result in any performance improvement over the FIND method.

Results of performance measures indicated the HMD and FIND modalities were significantly more accurate than the compass modality in terms of locating route waypoints. Consistent with this, the FIND and HMD modalities were rated significantly more acceptable than the compass on the Post-Mission Questionnaire for awareness of own location, awareness of waypoint locations, finding next waypoint after hazard, and determining when waypoint is reached. The HMD and FIND modalities were also rated significantly more acceptable than the compass for navigating around unforeseen hazard and accuracy for locating waypoints.

Several important issues were identified with the use of digital maps that can affect their utility in the field. Digital maps must display current data on the user's location and orientation; a slow update rate (i.e. slower than the mission pace) can result in route direction errors and navigation confusion. Similarly, the digital map display must rotate to match the facing direction of the user (i.e. orient the map to the ground) to avoid costly delays, route orientation reversals, and navigation confusion. Map details need to be scalable so that users can choose those layers of information that are required for the mission task at the time, thereby avoiding excessive display information. Issues with map icon sizing, zoom viewpoints, and other map features are discussed.

These results support the use of a digital map tablet for small unit commanders for use during route planning, mission briefings, and battlefield awareness during mission execution. A digital wayfinding aid (e.g. FIND) is supported for the rifleman tasked with the role of navigator or wayfinder, where the emphasis is reaching planned waypoints accurately while still making the best tactical use of the immediate ground and observing arcs for possible enemy forces.

Sommaire

Afin d'appuyer diverses tâches de navigation (par ex., planification de routes, séances d'information sur les missions, connaissance du terrain, orientation, connaissance du champ de bataille), l'information sur la navigation peut revêtir deux formes : la connaissance de la route et la reconnaissance du terrain. La connaissance de la route fait référence à l'information sur un itinéraire particulier sur le terrain, tandis que la reconnaissance fait référence à l'information sur un terrain plus vaste incluant la route à suivre (par ex., une carte). Alors que l'information permettant le repérage de la route est moins volumineuse que l'information de reconnaissance du terrain, elle tend également à être moins facile à adapter aux changements exigés au cours d'une mission de l'infanterie.

Peu de recherches ont été effectuées pour comparer l'utilité et la facilité d'utilisation des modèles de cartes numériques et des aides numériques à l'orientation avec d'autres outils classiques de navigation sur le terrain, pour la navigation à petite échelle et au niveau des petites unités et des soldats. Pour cette raison, cette expérience visait à étudier deux méthodes de visualisation qui contribuent principalement à la reconnaissance du terrain (soit une visualisation numérique par rapport aux cartes imprimées) et deux méthodes d'orientation qui contribuent principalement à la connaissance de la route (soit un système d'orientation numérique par rapport à la boussole). Cette expérience comparait trois combinaisons d'outils de reconnaissance et de repérage : une carte numérique avec une icône de direction à affichage sur visiocasque; une carte numérique à affichage sur tablette graphique avec un appareil audionumérique d'orientation (*Future Infantry Navigating Device* ou *FIND*); une carte topographique sur papier avec une boussole.

D'après les résultats, on a constaté que la carte numérique affichée sur tablette graphique avec l'appareil audionumérique d'orientation (FIND) obtenaient plus fréquemment la meilleure cote dans l'ensemble des questionnaires et des mesures de performance. Selon le questionnaire de départ, la méthode FIND s'est classée à un niveau beaucoup plus élevé que la carte imprimée en ce qui a trait à l'acceptabilité générale de la méthode. Les soldats ont déclaré que la méthode FIND offrait une grande exactitude aux fins de la navigation et qu'il était facile de garder le bon cap pendant l'utilisation du système. Ainsi, la méthode FIND a été jugée beaucoup plus acceptable que la carte imprimée et la boussole en ce qui concerne la facilité de suivre un itinéraire. D'après les mesures de performance, cette méthode a permis une bien meilleure exécution que la boussole pour réduire les écarts de la route prévue. En outre, la méthode FIND a obtenu des cotes beaucoup plus élevées que la carte numérique seule (visiocasque) pour ce qui est de déterminer la direction vers le point de cheminement.

Malgré l'appui important que les résultats des questionnaires et des mesures de performance apportent à la méthode FIND pour la navigation, on a identifié plusieurs problèmes à l'égard de la visualisation du terrain et de la planification des routes. D'après les réponses au questionnaire avant-mission, moins de 80 % des soldats ont jugé la méthode FIND acceptable pour la planification de la route, l'intégralité de la connaissance du terrain et la facilité d'interprétation de l'information. En raison de problèmes techniques, il n'était pas toujours possible d'actualiser la carte numérique afin d'afficher leur position exacte.

En général, la carte numérique seule avec l'affichage d'une icône de direction (sur visiocasque) recevait une cote supérieure à celle de la carte imprimée, mais inférieure à celle de la carte

numérique sur tablette graphique avec une aide audionumérique à l'orientation. La facilité d'estimation de la distance était le seul aspect pour lequel la carte numérique seule était jugée plus acceptable que la carte numérique sur tablette graphique avec l'aide audionumérique à l'orientation. Cette facilité d'estimation des distances sur la carte était corroborée par les mesures de performance, basées sur les erreurs d'estimation des relèvements des cibles de la mission, alors que la méthode FIND et le visiocasque permettaient une meilleure exactitude que la carte imprimée et la boussole. Cependant, cet outil n'a pas permis d'améliorer la performance par rapport à la méthode FIND.

Les résultats des mesures de performance ont indiqué que le visiocasque et la méthode FIND avaient une exactitude largement supérieure à celle de la boussole pour situer les points de cheminement le long de la route. Dans le même ordre d'idées, les méthodes utilisant le visiocasque et le FIND ont été jugées beaucoup plus acceptables que la boussole, d'après le questionnaire post-mission, notamment parce qu'elles permettaient au participant d'établir sa propre position et celle des points de cheminement, de trouver le point de cheminement suivant après avoir contourné un secteur dangereux et de déterminer si le point de cheminement avait été atteint. En outre, le visiocasque et le FIND étaient considérés beaucoup plus satisfaisants que la boussole pour contourner des dangers imprévus et pour situer des points de cheminement avec plus d'exactitude.

En ce qui concerne l'utilisation de cartes numériques, on a identifié plusieurs problèmes importants qui peuvent influencer leur utilité sur le terrain. Les cartes numériques doivent afficher des données actuelles sur la position et l'orientation de l'utilisateur; l'actualisation trop lente de la carte (c.-à-d. plus lente que le déroulement de la mission) peut occasionner des erreurs de parcours et de la confusion pour la navigation. De même, la carte numérique affichée doit tourner pour correspondre à la direction de l'utilisateur (c.-à-d. orientation de la carte en fonction du terrain) afin d'éviter des délais coûteux, l'inversement de la direction du parcours et la confusion dans la navigation. Les détails cartographiques doivent pouvoir s'adapter à des échelles variables afin de permettre aux utilisateurs de choisir les couches d'information nécessaires pour la mission au moment voulu, évitant ainsi l'affichage de renseignements superflus. Des problèmes relatifs à la taille des icônes, aux points de vue obtenus à l'aide de la fonction zoom et à d'autres caractéristiques cartographiques sont traités dans le présent rapport.

Pour les commandants de petites unités, les résultats de l'expérience soutiennent l'utilisation d'une tablette graphique pour l'affichage d'une carte numérique à des fins de planification de routes, de séances d'information sur les missions et de reconnaissance du champ de bataille pendant l'exécution d'une mission. L'utilisation d'une aide numérique à l'orientation (par ex. FIND) est souhaitable dans le cas d'un carabinier chargé de la navigation ou de l'orientation, dont la responsabilité consiste principalement à atteindre exactement les points de cheminement prévus, tout en faisant le meilleur usage tactique du milieu environnant et des arcs d'observation pour éventuellement repérer les forces ennemies.

Table of Contents

List of Tables

List of Figures

1 Introduction

Prior to navigating over ground or undertaking the tactical execution of a mission, soldiers perform a map reconnaissance to develop and internalize a mental model of the terrain, and plan their intended route. Soldiers consult their mental model during planning and decision-making in execution to derive the most effective courses of action prior to and during a mission. During the mission, soldiers often consult their map to maintain situation awareness, confirm their location, and to adapt to changes in the mission situation by creating a new plan. When executing the route plan, soldiers use a compass to select and maintain their bearing on a route and they count their paces to determine the distance traveled.

To support these activities, navigation information can be provided in two basic forms: route knowledge and survey knowledge. Route knowledge refers to information about a particular path in the terrain whereas survey knowledge refers to information about the larger terrain space with the associated route included (e.g. a map). While route knowledge information is less voluminous than survey knowledge information, it also tends to be less adaptable to the likely need for changes during an infantry mission.

There has been little research comparing the utility and usability of digital map models and digital wayfinding aids to other traditional terrain navigation tools for small-scale navigation at the small unit and individual soldier level. For this reason, this experiment investigated two visualization methods that contribute mostly to survey knowledge (i.e. digital versus paper map information) and two wayfinding methods that contribute mostly to route knowledge (i.e. digital wayfinding system versus compass).

2 Aim

The following aims were pursued in this trial:

- Investigate the utility of providing soldiers with a digital map for the purpose of open country terrain navigation.
- Evaluate the effectiveness and usability of alternative display modalities.
- Identify interface design aspects critical to optimize display design in the preferred modality(s).

3 Method

For the purposes of this experiment, participants were required to navigate 2 km routes through wooded terrain at Ft. Benning, Georgia using map and wayfinding aids in three system configurations: a digital map with a directional icon displayed on a helmet mounted display (HMD), a digital map displayed on a tablet with a digital audio wayfinding aid (FIND), and a paper topographic map with a compass. Participants trialed all three combinations in a repeated measures design. Presentation order of these combinations and the routes was balanced between participants to control for order effects. Three different route plans were used (i.e. a different route for each run) to minimize the learning effects of previous missions. This method is described in more detail in the following sections.

3.1 Participants

Twelve regular force infantry soldiers participated in the study. The soldiers ranged in age from 21 to 35 years (mean = 27.6). The group consisted of three privates (25%), six junior NCOs (50%) and three senior NCOs (25%). Seventy five percent of soldiers had 1 – 2 years in service and 25% had 3 – 4 years in service. Soldiers were also questioned regarding training and operational experience in patrolling and navigation operations. Few soldiers (8% of soldiers) had no navigation experience, 25% had some experience, 42% had moderate experience, and 25% had extensive navigation experience. All soldiers reported having normal or corrected-to-normal visual acuity and no hearing defects. During training, all soldiers indicated that they were able to perceive the graphics displayed on the digital map. No soldiers reported having experience using an HMD.

3.2 Apparatus

Several hardware and software systems were used to carry out this study. Soldiers in all conditions wore a data logging system on their backs. Soldiers in the HMD condition wore a navigation system on the vest in addition to a visual display modality worn on the head. Soldiers in the tablet with audio FIND condition wore a navigation system on the vest and a helmet equipped with loudspeakers. Each system and the associated sub-components are described in more detail below.

3.2.1 Data Logging System

For data collection purposes, all soldiers wore the Future Infantry Navigation Device (FIND) to log their course during wayfinding tasks. The FIND system was developed by Humansystems Incorporated® in conjunction with Oerlikon Contraves. The system was contained in a CF small-pack and consisted of a small Panasonic Toughbook laptop computer (Figure 1), a Garmin 12XL differential global positioning system (GPS) receiver, and the associated power supplies. Position coordinates of waypoints were preprogrammed into the computer. During the mission, the soldier's location, measured by the GPS was sampled and logged on the computer once every second.

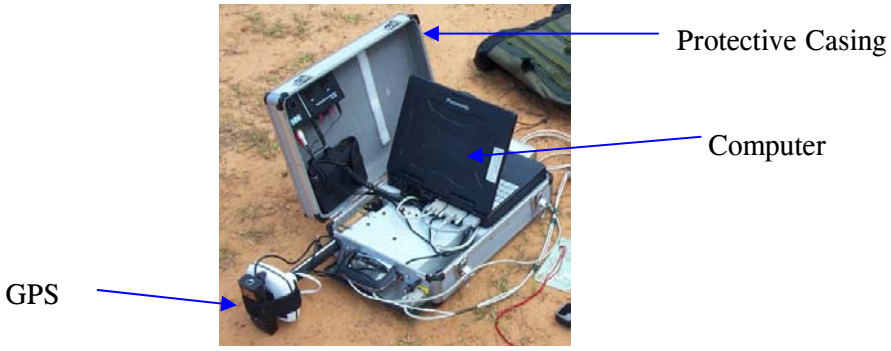

Figure 1: FIND system

A remote control device (see Figure 2) enabled experimenters to interrogate the distance to waypoint to verify proper system functionality, record the measurement point start and stop positions, mark the location of the perceived waypoint and start and stop the system for data recording.

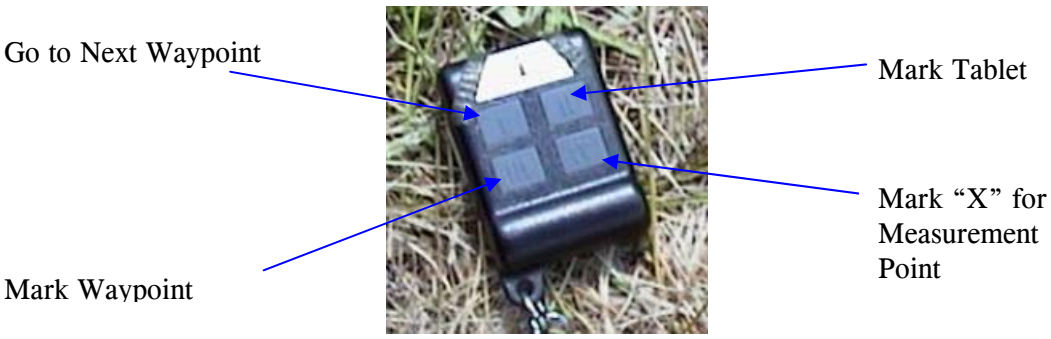

Figure 2: Remote control device

3.2.2 Land Warrior Navigation System

Land Warrior is a US Military program to increase survivability and lethality of soldiers in close combat. The Land Warrior Version 0.6 computerized land navigation component used in this experiment consisted of a very small, integrated navigation and global positioning system to indicate the position of the soldier on a digital topographic map. The digital map software

indicated terrain features, and enabled soldiers to plot both waypoints and the location of enemy and friendly forces. The software also included a measurement tool that provides distance estimates between any two points on the map.

The Land Warrior computer was installed inside silicon gel in a sealed metal pack about four inches wide, one and a half inches thick and eight inches long. The system was designed to accept a variety of peripherals including a HMD or LCD tablet. Soldiers interacted with the system using a rubber touchpad mouse attached to the front of the computer pack (see Figure 3). The system uses two Pentium systems: One system runs Windows 2000, particularly adapted for soldier use, and the other manages the total system. Rechargeable batteries were used for the experiment.

Figure 3: Land Warrior central processor and mouse

3.2.3 Digital Map Alone (Helmet Mounted Display)

The HMD used in this experiment was a Kaiser ProView SL35 full colour monocular SVGA display (see Figure 4).

Figure 4: Land Warrior HMD

The display position at the eye adjusted using a vertically telescoping rail attached to the helmet and a universal joint at the display attachment. The display input was connected to the Land Warrior computerized navigation system. A special helmet (i.e. MICH) designed for

compatibility with the Land Warrior was used for the experiment. Participants in the HMD condition were permitted to use the measurement tool provided by the Land Warrior system.

3.2.4 Audio FIND System

The FIND system was designed to provide a variety of sensory output modalities that can be configured to assist in soldier navigation. For the purpose of this experiment, the FIND system was configured to provide audio output through mono sound speakers incorporated into a CF helmet. The system analyzed input data from a GPS and compass (see Figure 5) and generated audio outputs to convey the degree to which the head was facing the direction of the active waypoint (see Figure 6).

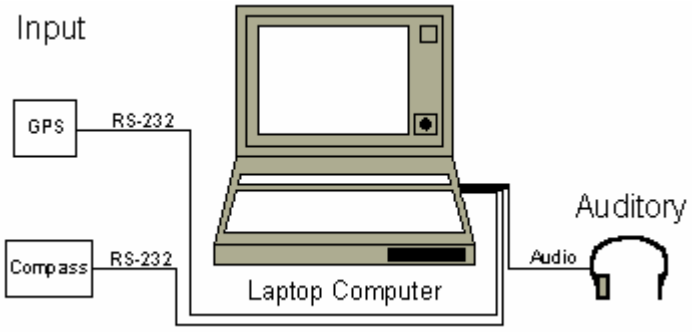

Figure 5: Audio FIND system schematic

The hardware and software systems related the soldier's own location (GPS) and facing direction (using an electronic compass on head) to the next waypoint. The difference between the facing direction and the waypoint bearing produced the offset bearing for soldier feedback.

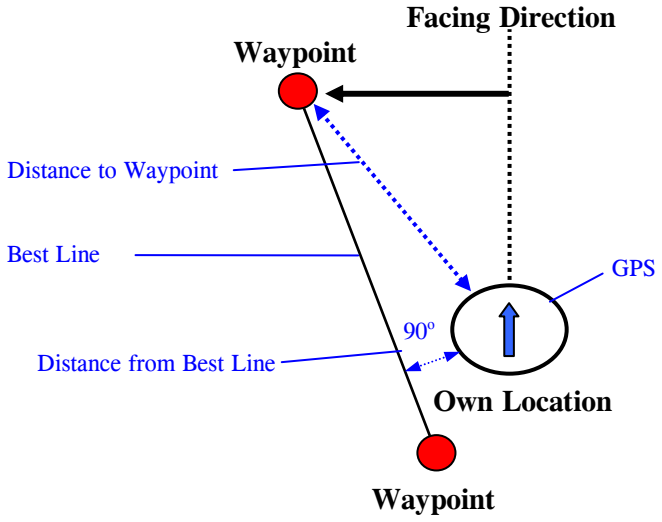

Figure 6: Wayfinding output data

As the soldier's head turned towards the direction of the next waypoint, both the pitch and the rate of the auditory tone increased in distinct levels. Each level represented a specific field of view (see Figure 7). When the soldier's head was facing within 8° of the waypoint, the tone was constant. The volume was adjustable, but set at a standard level during the run.

To operate the system, the soldier depressed a button on a remote control device mounted to the weapon to activate the auditory display. The soldier could then visually scan the way ahead while listening to the auditory frequency and pitch. The tone used was a synthesized oboe sound. Audio information was provided simultaneously to both ears. The tones changed in pitch and rate as the soldier turned his head. There were three different levels of tones, as shown in Figure 7.

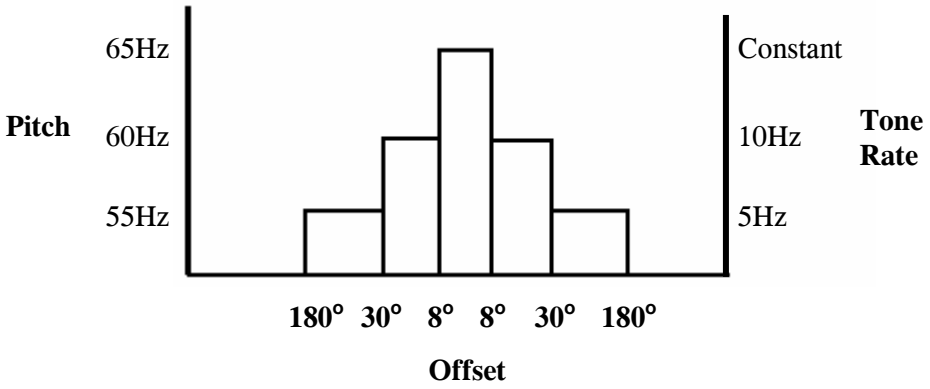

Figure 7: Auditory modality

3.2.5 Land Warrior Tablet

The tablet display used in the experiment was a VIA 8 inch SVGA (Super Video Graphics Array) full colour daylight readable LCD tablet. The display input was connected to the Land Warrior navigation system. Soldiers were able to interact with the touch screen using a stylus. The display could be carried in a pouch attached to the soldier's belt (see Figure 8). Participants in the tablet condition were not permitted to use the measurement tool provided by the Land Warrior system. A small analogue compass was attached to the tablet to help orient the map since the Land Warrior Navigation system always presented the map in a North-up orientation regardless of the facing direction of the soldier.

Figure 8: Land Warrior tablet worn with audio FIND system

3.2.6 Paper Map and Compass

A 2D topographic map was generated for each of the three routes using Delorme 3D Topoquads mapping software at 1:25000 scale. Maps were printed in colour and laminated in transparent plastic (see Figure 9).

Figure 9: Paper topographic map with compass

Map details included waypoints, route lines, magnetic North, and the compass declination. Military Grid Reference System (MGRS) gridlines were also provided.

3.3 Design

The design for the experiment was a fully balanced repeated measure design with three levels of the independent variable using the display modality. The conditions included: digital map alone (the Land Warrior HMD with digital topographic map); digital map and wayfinding aid (the Land Warrior tablet with digital topographic map) with the Audio FIND system; and paper map and compass which consisted of a paper topographic map and an analog compass.

3.4 Procedure

A fourteen-day field trial was undertaken at Ft. Benning, Georgia over the period of 11 – 24 December 2001. Soldiers were required to navigate routes with multiple waypoints through wooded terrain, using enhanced wayfinding information in three different display modalities: HMD, tablet with audio FIND, and paper topographic map with a compass. The order of the wayfinding modalities was balanced among soldiers.

Three different route plans were presented in a balanced order for each soldier to control for the effect of route difficulty (see Figure 10).

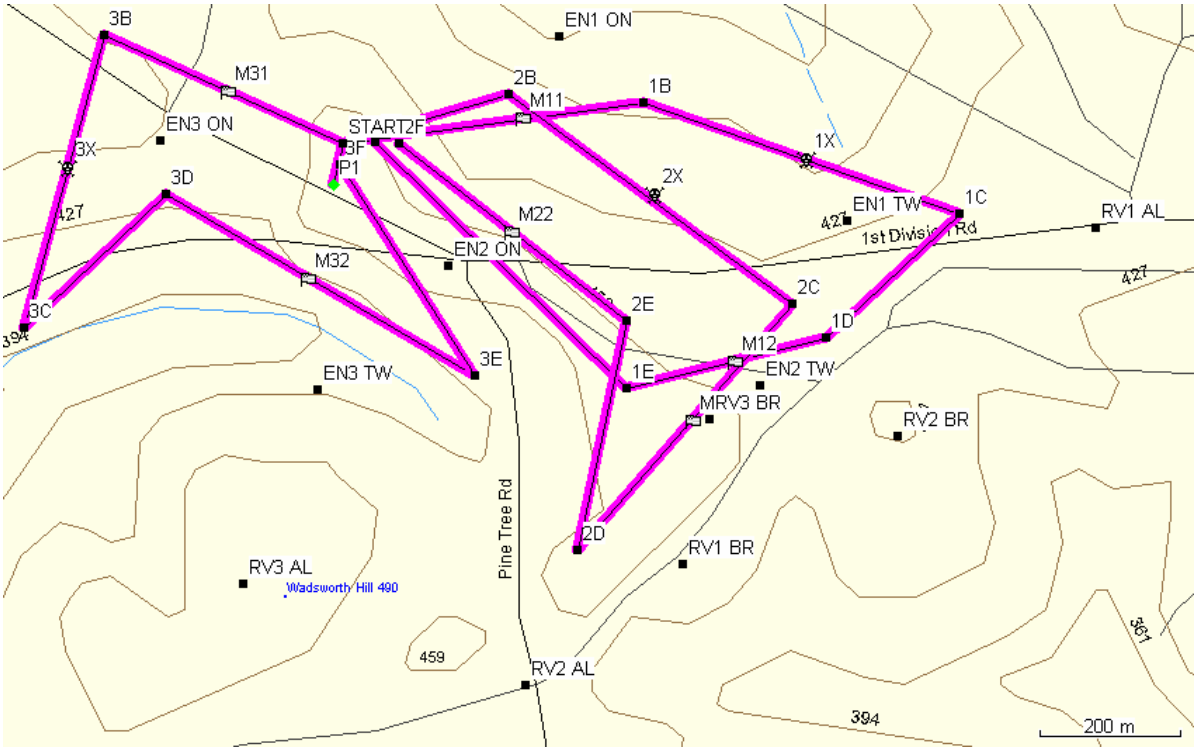

Figure 10: Wayfinding Routes & Measurement Point Locations[+]

[+] *Routes include: waypoints [e.g. Route 2 begins at "START" and ends at leg "2F"], measurement points [e.g. first measurement point on Route 1 is coded "M11"], known enemy locations [e.g. first enemy on Route 2 is coded "EN2 ONE"], friendly rendezvous points [e.g. second rendezvous point on Route 3 is coded "RV3 BRAVO"], and obstacles [e.g. the obstacle on Route 1 is coded "1X"].*

Each route was 2km in length and had five waypoints. All the routes started from the same location with each waypoint requiring a bearing change. Each route was configured to have as similar terrain, vegetation, and topography as possible.

The soldier was instructed that speed and accuracy were equally important when traveling from waypoint to waypoint. The soldiers were instructed to maintain their position on a straight-line course, deviating only as far as necessary to avoid natural and simulated obstacles.

3.4.1 Obstacles

To assess the adaptability of each wayfinding condition, route legs were planned in such a way as to require the soldier to confront and navigate around an unexpected simulated obstacle. An obstacle was incorporated into one leg of each route. The obstacle was on a different leg for each of the three routes. Obstacles were circular areas with a radius of 75 meters centered on the route line halfway between the waypoints that impeded the most direct route to the next waypoint. For the purpose of this experiment, the obstacles were referred to as minefields. The obstacle was deep enough and wide enough so that the soldier could not estimate its depth or width. At the waypoint prior to encountering an obstacle, the soldier was warned of the obstacle, provided the MGRS coordinate to the obstacle, instructed to navigate around it and to resume course to the active waypoint. For each obstacle, soldiers were instructed to go either left or right to standardize the direction traveled on a given route.

3.4.2 Measurement Points

To assess soldier awareness of known mission-critical features, enemy and friendly locations were indicated on the maps. At pre-determined measurement points, soldiers were stopped and asked to indicate the distance and bearing to selected enemy and friendly locations. The experimenter used a handheld GPS (see Figure 11) with the measurement point coordinates preprogrammed to identify when the soldier was within 50 meters of the measurement point. The experimenter also carried a stopwatch to record the time taken at the measurement points.

Figure 11: Garmin-eTrex GPS

At the measurement point, the experimenter instructed participants to provide bearing and distance to two objectives marked on the map. Soldiers using the compass modality were instructed to provide bearing and distance to objectives marked on the paper map. Soldiers using the HMD modality were able to query distances and bearings to the measurement points using the digital measurement tool provided by Land Warrior. Soldiers using the tablet with audio FIND were not permitted to use the Land Warrior measurement tool. Instead, soldiers used the audio FIND to orient themselves toward the next waypoint and rotated the tablet to align it with the next waypoint. Alternatively, soldiers had the option to use a small compass attached to the tablet to orient the map northward.

When the soldier was closest to a measurement point, the experimenter marked the location on the FIND system by pressing the "mark" button on the remote. These coordinates were used later to identify where the soldier was standing on the map when estimating the bearing and distance to the objectives. Before stepping off after the measurements were completed, the experimenter marked the location on the system a second time to log the duration of the measurement task to subtract this time from the total run time during data analysis.

3.4.3 Location

The content and density of terrain cues and the complexity of wayfinding can vary according to the type of terrain being traversed. To reduce the confounding effects of distinctive terrain reference cues, large sections of uniform, wooded terrain were selected for this study (Figure 12). The wooded areas selected included sufficient underbrush so as to limit the unobstructed visual distances available for wayfinding (i.e. placing more reliance on the wayfinding aides). These wooded areas also had little to no deadfall, thereby reducing the potential tripping hazards.

Figure 12: Wooded Terrain

3.4.4 Preparation and Pretests

Various questionnaires and forms were used to collect information. These are underlined below and detailed in the Annexes.

Following a briefing to all soldiers regarding the trial protocol, soldiers completed an ethics approved consent form to proceed with participation in the experiment. A Personal Information Questionnaire (see Annex A) was issued prior to the study, to obtain background information on

the soldiers and information regarding personally perceived navigational skill. This information included age, rank, years of experience, and navigation experience.

A battery of skill questionnaires was issued to assess spatial orientation, and spatial scanning. Performance on the spatial tests was then evaluated to ensure soldiers with a wide range of skill levels were included in the experiment.

At this time, soldiers also received instruction in the completion of the mental workload questionnaire, in accordance with the prescribed procedures of the National Aeronautics and Space Administration – Task Load Index (NASA TLX Workload Questionnaire). This is a technique developed by NASA to assess the relative importance of six factors in determining how much workload the individual experienced during the task.

These factors are mental demand, physical demand, temporal demand, performance, effort and frustration. Mental demand refers to the amount of mental and perceptual activity required for performing the task. Physical demand refers to the amount of physical activity required in performing the task. Temporal demand accounts for the time pressure resulting from the rate or pace of the task. Performance refers to perceived success in completing the task. Effort refers to how hard the individual had to work to complete the task while frustration level applies to how discouraged and irritated the individual was in performing the task.

On the day, prior to the start of the experiment, participants were each given familiarization with the digital maps and displays.

3.4.5 Wayfinding Tasks

Soldiers participated in one session for each of the three experimental conditions. Prior to the start of each session, a soldier was fitted with the appropriate equipment for the experimental condition. The soldier was allowed 10 minutes to study and visualize the preplanned route, using the assigned map condition. Following terrain visualization, the map was removed and the soldier was required to draw the map from memory including terrain features, route lines, waypoints, and enemy and friendly locations. Next, soldiers were required to complete a Pre-Mission Questionnaire (see Annex B). The Pre-Mission Questionnaire was used to obtain ratings of effectiveness, confidence in the visualization method, mental workload, overall ratings and comments.

Prior to starting the navigation session, a systems check was conducted to ensure that the system was functioning properly and collecting data. Two test waypoints, separate from the experimental routes, were laid out for the soldiers to familiarize themselves with the system. The experimenter conducted crosschecks of the system to ensure it was logging the soldier's position correctly. Once the familiarization run had concluded, the experimenter activated the start point on the experimental route using the "next waypoint" button on the remote.

The trial began with the experimenter and soldier at the start point of the wayfinding route. The start of the experiment was marked on the logging system by the selection of the first waypoint.

Participants were instructed that speed and accuracy were equally important when traveling from waypoint to waypoint. The soldiers were instructed to maintain their position on a straight-line course, deviating only as far as necessary to avoid obstacles.

At various points throughout the route, the soldier looked at their current position, the route line, and position of the waypoint on the map. The GPS data logging system recorded the soldier's raw coordinates and distance from the waypoint every second. For each raw coordinate, the time at which the coordinate was collected (relative to the start time) was recorded.

The system displayed auditory confirmation, "Twenty meters to waypoint", when the soldier was 20 meters away from the active waypoint. This was meant to act as positive reinforcement that the soldier was on the right track and nearing his destination. The auditory confirmation was displayed in all three conditions. After the confirmation was presented, the soldier stopped, interrogated the system for a final bearing check and did a pace count for the remaining 20 meters.

When the soldier believed that he had reached the waypoint, the soldier stopped and verbally indicated to the experimenter by saying "Finished." The experimenter recorded the location and time on the data file by pressing the "waypoint reached" button on the remote. The experimenter initiated the start of the next leg of the route pressing the "next waypoint" button on the remote. The computer displayed an auditory confirmation when the "next waypoint" button was pressed to confirm that the system had switched over to the next waypoint. If the system did not switch over, the system would verbally indicate the name of the current waypoint. The interface was set to enable the experimenter to switch the system to the next waypoint only within 500 meters of the active waypoint. This was done to prevent repeated accidental button presses advancing the system to the incorrect waypoint.

Following the completion of the route, subsequent analyses included calculations of total distance traveled, total time, velocity, RMS error, and distance from endpoint. These were calculated for each leg and for the overall route.

Immediately following completion of the route, participants were required to complete a NASA TLX Workload Questionnaire (see Annex C) and a Post-Mission Questionnaire (see Annex D). The Post-Mission Questionnaire was used to obtain ratings of effectiveness, ease of use, wayfinding effectiveness, overall ratings and comments.

For the purposes of this study, orientation and route decisions were established for the soldiers. Orientation traditionally involves determining where one is in respect to nearby objects and the target location (landmarks). Traditional comparisons between a map and landmarks to orient oneself will be enhanced by an exact grid location indicated on the digital map corresponding to GPS co-ordinates. Route decision traditionally involves choosing a route that will get one to their destination. A predetermined route with specified waypoints, distances, and bearings, was provided to facilitate the wayfinding exercise. Route monitoring involves monitoring the route one has taken to confirm that one is on the correct route and is going in the right direction. The primary measure of route monitoring performance includes the distance from the route and the total distance traveled. Destination recognition involves recognizing that one has reached the correct destination, or at least a point nearby. The primary measure of destination recognition includes the accuracy (in distance) of the waypoint estimations.

An Exit Questionnaire (see Annex E) was administered after the Post-Mission Questionnaire once the final route was completed. The Exit Questionnaire was used to obtain comparison ratings between the different display modalities.

A focus group discussion was conducted with all soldiers to elicit group commentary and promote discussion regarding the usability and utility of the displays for the various modalities.

3.4.6 Acceptance Measures

The Pre-Mission, Post Mission, and Exit Questionnaires used a seven-point rating scale of acceptability, where 7 is "Completely Acceptable" and 1 is "Completely Unacceptable" (see Figure 13).

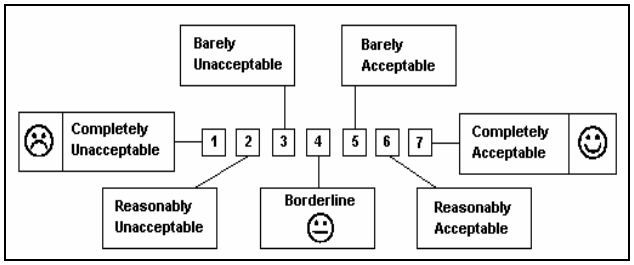

Figure 13: Seven-point rating scale of acceptability

3.4.7 Wayfinding Performance Measures

The route adopted by the soldier was tracked by a differential GPS (+/- 2m) and compared to the route plan to determine:

- Track deviation: The extent of track deviation from the most direct route between waypoints was determined for each leg (see Figure 14) and totaled for the route (RMSE or root mean square error).

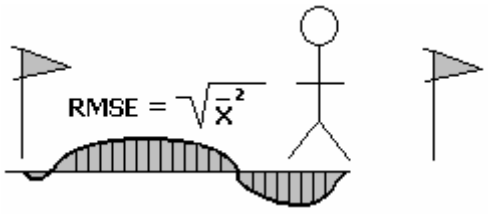

Figure 14. Root Mean Squared Error (RMSE)

- Obstacle avoidance: For each obstacle, soldiers were required to navigate around the obstacle in the most efficient manner. Each soldier's closest distance from the minefield was measured and evaluated. Participants 75m or closer to the hazard were counted as having crossed the minefield.
- Time to waypoint: Time to traverse each leg and each route (see Figure 15).

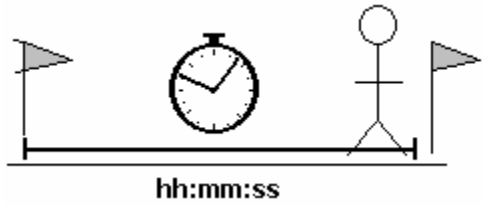

Figure 15. Time to waypoint

- Total distance traveled: Total distance traveled for each leg and each route was calculated (see Figure 16).

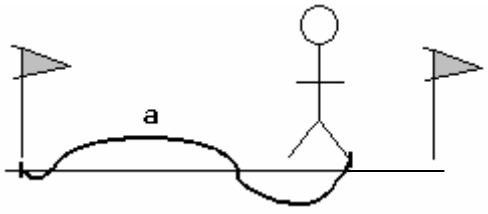

Figure 16. Time to waypoint

- Distance to endpoint: Soldiers were instructed to stop when they had reached the waypoint. The distance from the actual waypoint location and the soldier's location was calculated (see Figure 17). This was used as the primary measure of destination recognition.

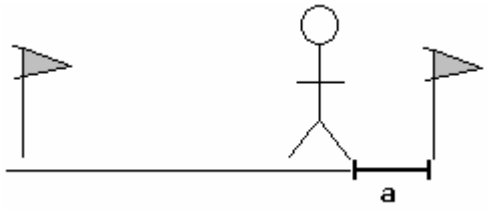

Figure 17. Distance to endpoint

- Accuracy of bearing and distance estimation: Soldiers were stopped on two occasions during the course of walking the route and were required to estimate the distance and bearing to one enemy and one friendly position shown on the digital map. The distance and bearing from each position shown on the map and the soldier's actual position was measured using data analysis software.
- NASA TLX workload: Overall workload scores for each modality.

4 Results

This section presents the results obtained from analysis of the objective and subjective measures used during the wayfinding experiment. The results have been divided into separate categories that include navigation, terrain visualization and route planning, ease of use, and overall evaluation of the system. Each section individually assesses results obtained from the performance measures (if applicable), Pre-Mission and Post-Mission Questionnaires, and Exit Questionnaires. Comments from soldiers are described to help interpret the obtained results.

A repeated-measures analysis of variance was conducted for all measures (n = 12). Follow-up analyses were conducted with a Tukey test. Significant differences were identified at $p \leq .05$. The abbreviations used in the tables to represent the different modalities include: "F" for tablet with audio FIND, "H" for HMD, and "C" for paper map with compass. The following icons were used in the tables to represent each of the three experimental conditions:

- Digital map alone  H
- Digital map and wayfinding aid  F
- Paper map and compass  C

Tables provide the mean acceptance ratings for each modality, as well as the percentage of participants that rated the item "Acceptable," corresponding to a rating of "Borderline" (≥ 4) or greater on the 7-point acceptability scale. Items rated acceptable by less than 80% of participants were shaded to highlight their potential non-compliance with a common standard of acceptance.

4.1 Participant Characteristics

A wayfinding experience questionnaire was used to obtain information regarding perceived skill at land navigation: Sixteen percent of soldiers rated their land navigation skills as "excellent", 66% percent rated their skills as "good", 8% rated their skills as "fair", and 8% rated their skills as "poor".

A battery of cognitive skill questionnaires was used, to assess spatial scanning, orientation, and memory. An overall score from 1 to 30 was calculated for the results. A higher score was representative of better cognitive skill. Cognitive ability tests were taken prior to the start of the experiment. The overall scores ranged from 9.5 to 29.5 (mean =20.6).

4.2 Effectiveness for Navigation

Participants were required to assess the effectiveness of the visual and auditory modalities using the Land Warrior and the FIND systems to navigate a predetermined route. The results are discussed in this section.

4.2.1 Performance Measures: Navigation

Waypoint 5 was not included in the performance analysis for navigation because soldiers could see or hear the base camp on their approach to waypoint 5. A separate analysis for waypoint 4 was conducted because waypoint 4 was the final waypoint participants were required to find before returning in the direction of the base camp, and it was considered a good representation of wayfinding performance.

Performance measures included accuracy of endpoint estimation, track deviation, time to traverse the ground, and total distance traveled. The results from the navigational performance measures are illustrated in Table 1 and discussed below.

Table 1. Performance measures for navigation

	Performance Means and Standard Deviations			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
Distance to Endpoint				
Distance to Endpoint (meters) for Waypoints 1-4	11.9 ±5.37	25.4 ±12.18	109.4 ±92.25	F, H < C
Distance to Endpoint (meters) for Waypoint 4	20.8 ±10.30	10.6 ±8.27	98.9 ±113.88	F, H < C
Track Deviation				
Mean RMS Error (meters) for Waypoints 1-4	64.5 ±21.47	46.6 ±19.88	86.9 ±58.77	F < C
Mean RMS Error (meters) for Waypoint 4	55.2 ±24.19	26.3 ±16.44	71.8 ±68.85	F < C F < H *
Time to Traverse the Ground				
Total Time (minutes) to Waypoint 1-4	0:52:18 ±15:06.1	0:49:59 ±8:52.8	0:56:27 ±8:40.8	ns
Time (minutes) to Waypoint 3-4	0:09:14 ±3:42.5	0:08:13 ±2:45.3	0:10:15 ±4:21.3	ns
Total Distance Traveled				
Total Distance Traveled (meters) for Waypoints 1-4	2289.6 ±255.46	2157.2 ±204.90	2447 ±606.71	ns
Total Distance Traveled (meters) for Waypoints 3-4	448.4 ±91.10	407.7 ±89.59	460.7 ±210.61	ns
Obstacle Avoidance				
Closest Distance to Minefield (meters)	30.2 ±20.62	42.1 ±22.42	42.4 ±35.15	ns
Percent of Soldiers to Avoid Minefield	7 %	0 %	14 %	ns

[+] *Significant Effect: p < 0.05: F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*
** Marginally significant effect: p < 0.07*

For distance to endpoint, the FIND and HMD modalities attained a significantly lower mean distance to endpoint (meters) for waypoints 1 to 4 as compared to the compass modality (see Figure 18) as well as a lower mean distance to endpoint (meters) for waypoint 4 alone (see Figure 19). This result can likely be attributed to GPS functionality that enabled soldiers to identify their position relative to the waypoint without requiring the use of landmarks or the counting of paces. Endpoint error (i.e. distance) was significantly greater with compass use even though this wayfinding task was performed during ideal daylight conditions. Highly variable endpoint error for soldiers using a compass further indicates that FIND and HMD performance was more reliable and less dependent on idiosyncratic soldiering skills.

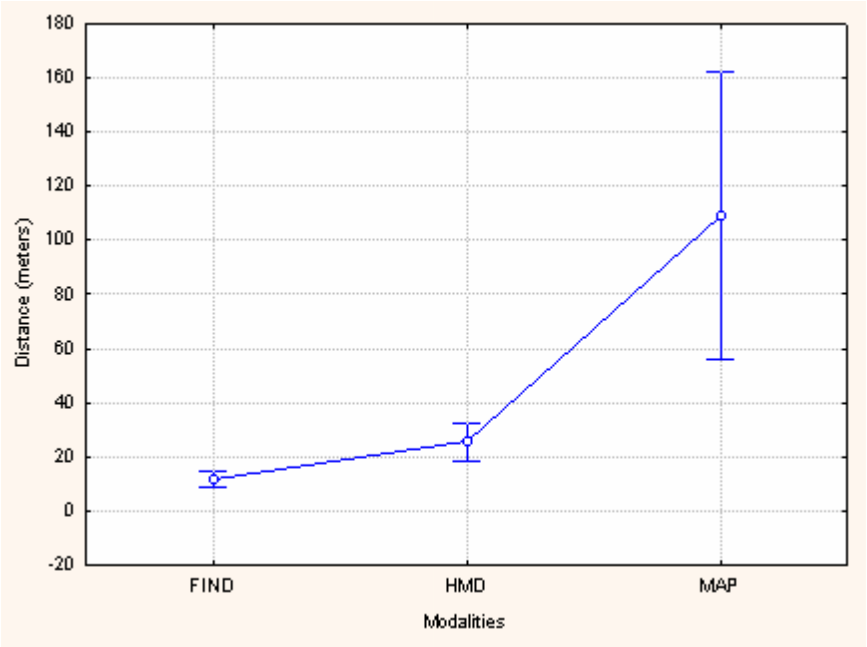

Figure 18: Distance to endpoint (meters) for waypoints 1-4

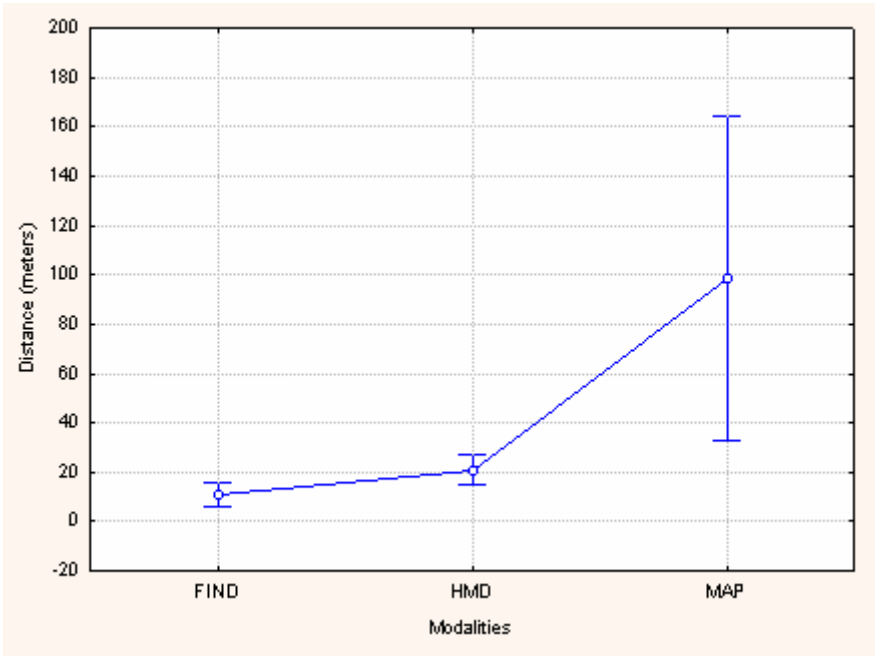

Figure 19: Distance to endpoint (meters) for waypoint 4

For track deviation (N=12), the FIND system attained significantly lower average RMS (Root Mean Square) error than the compass modality for legs 1 to 4 (see Figure 20) and for leg 4 alone (see Figure 21). This may be attributed to the ability of soldiers to stay on course toward the waypoint at all times by accessing the FIND system while moving. In contrast, the compass did not provide accurate heading information while moving because of the difficulty in stabilizing the compass, requiring soldiers to visually detect target observable features to maintain their bearing line. This visual requirement is difficult to achieve at night or in poor visibility conditions.

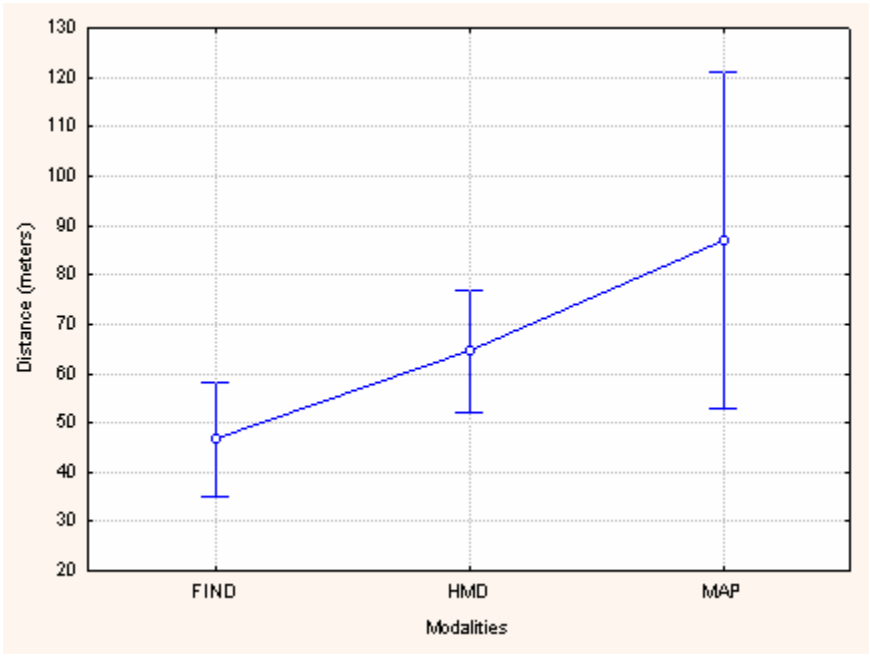

Figure 20: Mean RMS error (meters) for waypoints 1-4

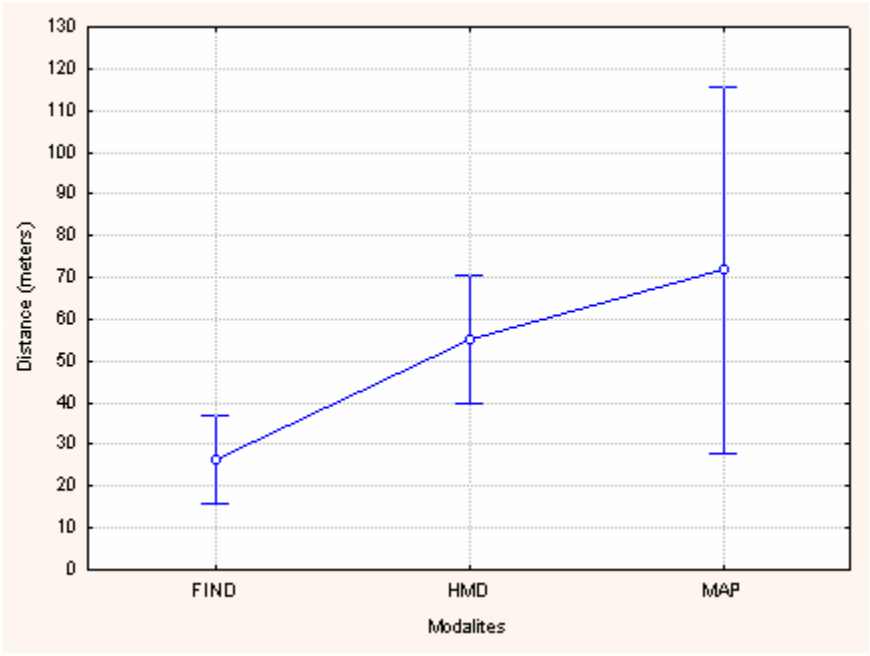

Figure 21: Mean RMS error (meters) for waypoint 4

For time to traverse the ground, there was no significant difference among modalities regarding time to waypoint for waypoints 1 to 4 or for time to waypoint for waypoints 3 to 4. Also, no significant difference was found among modalities for total distance traveled for waypoints 1 to 4 or for waypoints 3 to 4.

While the FIND system performance indicated a trend toward lower traverse times and shorter distance traveled, there was high variability in the data in all of the conditions (especially the compass condition).

For obstacle avoidance, no significant differences were found regarding the closest distance to the minefield. However, over 80% of soldiers failed to avoid the minefield in every condition. No soldiers in the FIND condition were able to avoid the minefield. Only 7% of soldiers in the HMD condition avoided the minefield and 14% of soldiers in the compass modality were able to avoid the minefield. Poor performance in this task indicates a serious usability problem for the obstacle avoidance task that requires further investigation.

4.2.2 Post-Mission Questionnaire Results: Navigation

The results from the Post-Mission Questionnaire for navigational performance are illustrated in Table 2 and discussed below.

Table 2: Post-Mission Questionnaire acceptance ratings for navigation

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
1. Use While Moving	5.4	5.3	5.3	ns
	71 %	86 %	79 %	
2. Use While Stationary	5.4	6.3	5.9	ns
	79 %	86 %	93 %	
3. Speed of Terrain Traverse	5.6	6	5.8	ns
	92 %	93 %	79 %	
4. Ease of Relating Terrain to Visualization Method	5	5.7	5.4	ns
	79 %	93 %	71 %	
5. Determining Direction to Waypoint	5.4	6.4	5.9	H < F
	71 %	100 %	93 %	
6. Determining When Waypoint is Reached	5.9	5.9	4.8	C < F, H
	86 %	93 %	64 %	
7. Navigating Around Hazard	5	5.4	4.8	ns
	79 %	79 %	64 %	
8. Ease of Finding Next Waypoint After Hazard	5.9	6.4	4.8	C < F, H
	86 %	100 %	64 %	
9. Amount of Information Presented	6	5.9	5.6	ns
	86 %	79 %	79 %	
10. Accuracy of Information Presented	5.1	5.6	5	ns
	64 %	71 %	64 %	
11. Awareness of Own Location	5.9	6.1	4.8	C < F, H
	95 %	100 %	95 %	

[+] *Significant Effect: p < 0.05: Shaded areas indicate item rated acceptable by less than 80% of soldiers. ns = not significant F = FIND System, H = Helmet Mounted Display, C = Compass*

The FIND modality attained significantly higher acceptance ratings as compared to the HMD modality for determining the direction of the next waypoint in the Post-Mission Questionnaire. The HMD modality was rated acceptable by less than 80% of soldiers for determining direction to waypoint. Soldiers' comments revealed that this rating was attributed to the reported inability of the Land Warrior to accurately indicate soldier locations to an accuracy of less than 20 to 30 meters. This may have been a result of slow updates of the display or GPS dropouts. Low acceptance ratings of the HMD for determining direction to waypoint may also be attributed to the fact the Land Warrior required soldiers using the HMD to be in motion to obtain an accurate differential GPS heading to determine their bearing. Further, participants indicated the position update rate was too slow on the display.

The HMD and FIND modalities also attained significantly higher acceptance ratings in comparison to the compass with regard to the ease of finding the next waypoint after avoiding the hazard. Less than 80% of soldiers rated the compass as acceptable for the ease of finding the next waypoint after the hazard. This highlights a limitation of using a compass, where the

soldier must compensate for offsets to ensure that s/he is on the right bearing. In contrast, the FIND system constantly recalculated the bearing of the soldier relative to the waypoint; this feature that was much preferred and emphasized in evaluation comments.

The HMD and FIND modalities attained significantly higher ratings than the compass modality with regard to determining when waypoint is reached and awareness of own location. Less than 80% of soldiers rated the compass as acceptable for determining when a waypoint is reached. Participants attributed their acceptance of the HMD and FIND modalities to their ability to use the GPS to identify their position relative to the waypoint. Correspondingly, soldiers indicated their dislike for determining distances by counting paces using the map and compass, as this can result in questions regarding the exact location of the waypoint.

Soldiers overestimated their ability to navigate around the hazard using the HMD and FIND systems. Both systems achieved an acceptable mean rating for navigating around the hazard despite the fact that over 80% of soldiers crossed the minefield for each condition.

The HMD and compass were rated acceptable by less than 80% for use while moving and for ease of relating terrain to visualization method. Less than 80% of soldiers rated all three systems as acceptable for navigating around hazards, and for the accuracy of information presented. Soldiers experienced a great deal of difficulty avoiding the hazard as evidenced by the poor performance measures for hazard avoidance. This may have negatively influenced their ratings of the accuracy of information provided to them by the modalities.

Less than 80% of soldiers rated the FIND system and compass acceptable in terms of the amount of information presented. One interpretation of this result is that the FIND system presented too much information (both auditory and visual), while the compass modality did not present enough information. Less than 80% of soldiers rated the HMD acceptable for use while stationary. Less than 80% of soldiers rated the compass acceptable for speed of terrain traverse.

4.2.3 Exit Questionnaire Results: Navigation

The results from the Exit Questionnaire regarding operation are illustrated in Table 3 and discussed below.

Table 3: Exit Questionnaire acceptability ratings for navigation

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
1. Ease of Navigating Route	5.9	6.2	5.1	C < F
	100 %	93 %	93 %	
2. Awareness of Own Location	5.9	6	4.8	
	86 %	93 %	71 %	
3. Awareness of Mission Features	5.7	5.9	5.4	
	79 %	86 %	79 %	
4. Accuracy of Method for Real Terrain Layout	5.2	5.1	5.4	
	71 %	64 %	79 %	
5. Accuracy of Method for Real Distances	6	5.5	5.6	
	93 %	93 %	93 %	
6. Navigating Around Unforeseen Hazard	5.7	5.7	4.6	C < F, H
	70 %	79 %	57 %	
7. Ease of Relating Method to the Ground	5.5	5.2	5.4	
	71 %	71 %	86 %	
8. Terrain Recognition	5.3	5.2	5.4	
	79 %	86 %	93 %	
9. Maintaining Orientation to the Ground	5.5	6	5.5	
	79 %	79 %	79 %	
10. Accuracy for Locating Waypoints	6.2	6.4	4.4	C < F, H
	93 %	93 %	50 %	
11. Confidence in System	5.8	6	5.6	
	93 %	100 %	86 %	

[+] *Significant Effect: p < 0.05: Shaded areas indicate item rated acceptable by less than 80% of soldiers.*
F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant

Exit Questionnaire results indicate the FIND modality attained significantly higher acceptance ratings as compared to the compass modality for ease of navigating route. Further, the FIND and HMD modalities attained significantly higher acceptance ratings compared to the compass modality for accuracy for locating waypoints. The compass modality was rated acceptable by less than 80% of soldiers for accuracy of locating waypoints and for awareness of own location. These results may be attributed to advantages provided by the GPS included in the FIND and HMD conditions.

In terms of terrain recognition, the HMD modality was rated acceptable by less than 80% of soldiers. Further, the FIND and HMD modalities were rated acceptable by less than 80% of participants for ease of relating method to the ground. Also, less than 80% of soldiers rated the HMD and compass modalities acceptable for awareness of mission features. These results indicate usability problems orienting the map to the ground with a particular bias against the HMD.

While all modalities were rated acceptable by less than 80% of soldiers for navigating around unforeseen hazards, soldiers once again overestimated their ability to navigate around the hazard using the HMD and FIND systems. The FIND and HMD modalities attained significantly higher acceptance ratings compared to the compass modality for navigating around unforeseen hazard despite the fact that over 80% of soldiers crossed the minefield for each condition.

Similarly, all modalities were rated acceptable by less than 80% of soldiers for accuracy of method for real terrain layout and for ease of maintaining orientation to ground. These findings are consistent with the performance measures, suggesting serious usability problems for all modalities with regard to obstacle avoidance. No significant differences were found for:

- Awareness of own location,
- Awareness of mission features,
- Accuracy of method for real terrain layout,
- Accuracy of method for real distances,
- Ease of relating method to the ground,
- Terrain recognition,
- Maintaining orientation to the ground, and
- Confidence in system.

4.2.4 Navigation Summary

With regard to navigation, the FIND modality performed best and the compass performed worst. The HMD performed nearly as well as the FIND modality with the exception of ratings for use while stationary, use while moving, and determining the direction to waypoint. Performance measures indicated the FIND and HMD modalities attained significantly lower distance to endpoint as compared to the compass modality. Results of the Post-Mission Questionnaire also indicated the HMD and FIND attained significantly higher acceptance ratings than the compass for determining when the waypoint was reached, with less than 80% of soldiers rating the compass acceptable on this item. These results are consistent with the Exit Questionnaire, which showed the FIND and HMD modalities attained significantly higher acceptance ratings compared to the compass modality for accuracy in locating waypoints, with the compass modality rating acceptable by less than 80% of soldiers on this item.

Performance measures for deviation from track indicated the FIND system performed best and the compass modality performed worst. The FIND modality attained significantly less mean RMS error than the compass modality. Exit Questionnaire results showed the FIND modality attained significantly higher acceptance ratings as compared to the compass modality for speed of

terrain traversal and ease of navigating route. Less than 80% of soldiers rated the HMD acceptable for use while stationary and less than 80% of soldiers rated the compass acceptable for speed of terrain traversal. In terms of use while moving, the HMD and compass were rated acceptable by less than 80% of soldiers on the Post-Mission Questionnaire. The FIND modality attained significantly higher acceptance ratings for determining direction to waypoint compared to the HMD modality on the Post-Mission Questionnaire. The HMD modality was rated acceptable by less than 80% of soldiers for determining the direction to waypoint. With regard to ease of finding waypoint after hazard, the HMD and FIND modalities attained significantly higher acceptance ratings in comparison to the compass. Less than 80% of soldiers rated the compass acceptable for ease of finding waypoint after hazard.

Serious usability problems were identified for all modalities with regard to avoiding the hazard. Performance measures showed in every condition over 80% of soldiers crossed the minefield. Only 7% of soldiers in the HMD condition avoided the minefield and 14% of soldiers in the compass modality were able to avoid the minefield. No soldiers using the FIND modality were able to avoid the minefield. This is consistent with results of the Post-Mission Questionnaire that indicated less than 80% of soldiers rated any of the three systems acceptable for navigating around hazard and for the accuracy of information presented. Exit Questionnaire results also indicated less than 80% of soldiers rated any of the modalities acceptable for navigating around unforeseen hazards.

In terms of situation awareness, all the modalities had weaknesses. The Post-Mission Questionnaire indicated less than 80% of soldiers rated the FIND system and compass acceptable in terms of the amount of information presented. The HMD and compass were rated acceptable by less than 80% of soldiers on the Post-Mission Questionnaire in terms of ease of relating terrain to visualization method. The FIND and HMD modalities were rated acceptable by less than 80% of soldiers on the Exit Questionnaire for ease of relating method to the ground, and less than 80% of soldiers rated all modalities acceptable for ease of maintaining orientation to ground. The FIND and HMD were rated significantly more acceptable than the compass for awareness of own location on the Post-Mission Questionnaire. Consistent with this, less than 80% of soldiers rated the compass modality acceptable on the Exit Questionnaire for awareness of own location.

Additional problems were identified with the HMD and compass modalities for terrain recognition. Less than 80% of soldiers rated the HMD modality acceptable on the Exit Questionnaire for terrain recognition. Less than 80% of soldiers rated the HMD and compass modalities acceptable for awareness of mission features and less than 80% of soldiers rated any of the modalities acceptable for accuracy of method for real terrain layout.

4.3 Terrain Visualization and Route Planning

Soldiers were required to visualize natural and artificial obstacles indicated on the digital map. This section assesses the ability of soldiers to effectively visualize their location on the ground and to identify the bearing and distance to objects indicated on the three map modalities.

Soldiers were required to assess the effectiveness of using the digital maps to plan a predetermined route. The results are discussed in this section.

4.3.1 Performance Measures: Terrain Visualization and Route Planning

Performance measures included accuracy of bearing and distance estimation. The results from the terrain visualization and route planning performance measures are illustrated in Table 4 and discussed below.

Table 4: Performance measures for train visualization and route planning

	Means and Standard Deviations			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
Error Estimating Bearing (degrees)	15.1 ±20.77	18.7 ±15.09	30.9 ±35.28	F, H < C
Error Estimating Distance (meters)	43.8 ±93.59	86.3 ±108.89	86.9 ±130.07	ns

[+] *Significant Effect: p < 0.05. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*

Within subjects analysis of variance from subjective scores for error estimating bearing to objective indicated significant differences (at $p < 0.05$) between the display modalities (see Figure 22).

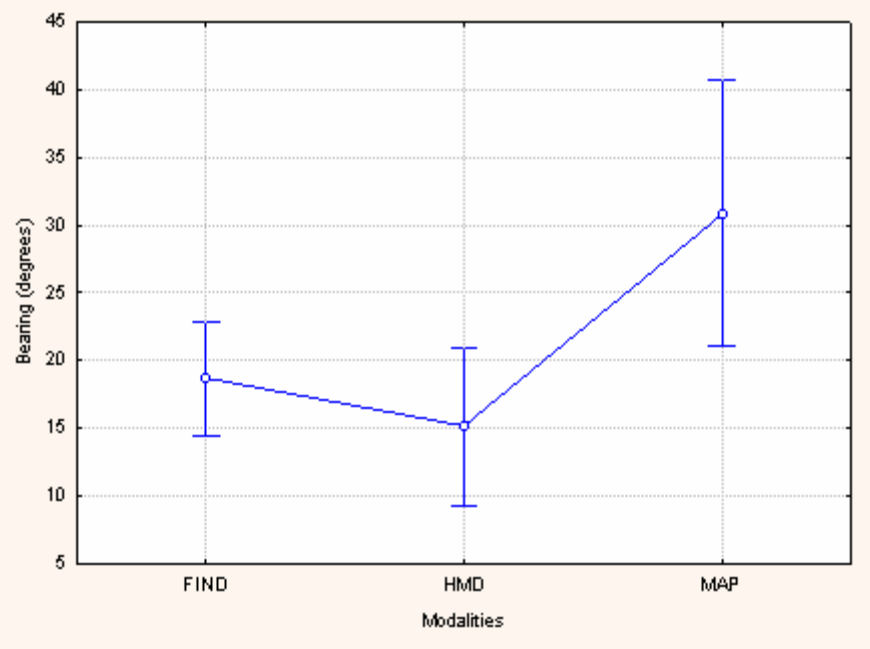

Figure 22: Error estimating bearing (degrees)

Tukey pairwise comparisons indicated soldiers estimated the bearing to the objective significantly more accurately using the FIND system and HMD (at $p < 0.05$) than using the compass. This may be attributed to the measurement tool provided by the Land Warrior system and to soldiers' ability to use the GPS to accurately identify their position relative to the measurement point.

No significant differences were found regarding cumulative error estimating the distance to the objectives.

4.3.2 Pre-Mission Questionnaire Results: Terrain Visualization and Route Planning

The results from the Pre-Mission Questionnaire regarding terrain visualization and route planning are illustrated in Table 5 and discussed below.

Table 5: Pre-Mission Questionnaire results for terrain visualization and route planning

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) p < 0.05
	HMD	FIND	Compass	Modality
1. Route Planning	6	5.6	5.9	ns
	93 %	79 %	93 %	
2. Awareness of Terrain Layout	5.9	5.8	5.8	ns
	86 %	86 %	93 %	
3. Accuracy of Terrain Knowledge	5.6	5.4	5.5	ns
	79 %	86 %	86 %	
4. Completeness of Terrain Knowledge	5.6	5.3	5.5	ns
	86 %	71 %	86 %	
5. Awareness of Mission Features	6	5.6	5.8	ns
	93 %	86 %	86 %	
6. Confidence for Planning Route	6	5.9	6	ns
	86 %	93 %	93 %	
7. Confidence for Navigating Terrain	5.8	5.9	5.6	ns
	86 %	93 %	93 %	

Shaded areas indicate item rated acceptable by less than 80% of soldiers. ns = not significant

There were no significant differences among modalities to report. However, less than 80% of soldiers rated the FIND system acceptable for effectiveness for route planning and completeness of terrain knowledge, and less than 80% of soldiers rated the HMD acceptable for accuracy of terrain knowledge.

4.3.3 Post-Mission Questionnaire Results: Terrain Visualization and Route Planning

The results from the Post-Mission Questionnaire regarding terrain visualization and route planning are illustrated in Table 6 and discussed below.

Table 6: Post-Mission Questionnaire results for terrain visualization and route planning

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
1. Awareness of Terrain Layout	5.4	5.9	5.7	ns
	79 %	93 %	86 %	
2. Terrain Reconstruction	4.8	5.5	5	H < F
	70 %	95 %	95 %	
3. Awareness of Mission Feature Locations	5.9	5.8	5.4	ns
	86 %	79 %	79 %	
4. Awareness of Waypoint Locations	6.2	6.3	5.4	C < F, H
	100 %	100 %	95 %	

[+] *Significant Effect: p < 0.05: Shaded areas indicate item rated acceptable by less than 80% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not signficant*

Post-Mission Questionnaire results for terrain visualization and route planning indicate the FIND and HMD modalities attained significantly higher ratings than the compass modality with regard to awareness of waypoint locations. This may be attributed to the GPS functionality provided by the FIND and HMD that enabled soldiers to identify their position relative to the waypoint at all times. The FIND modality also attained significantly higher ratings than the HMD for terrain reconstruction. No significant differences were found for awareness of terrain layout and for awareness of mission feature locations.

Less than 80% of soldiers rated the HMD acceptable for awareness of terrain layout and terrain reconstruction. Less than 80% of soldiers rated the FIND system and map and compass acceptable for awareness of mission feature locations.

4.3.4 Exit Questionnaire Results: Terrain Visualization

The results from the Exit Questionnaire regarding terrain visualization are illustrated in Table 7 and discussed below.

Table 7: Exit Questionnaire results for terrain visualization

	Mean performance rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) $p < 0.05$
	HMD	FIND	Compass	Modality
1. Creating Mental Image of the Ground	5.2	5.2	5.5	ns
	79 %	71 %	93 %	
2. Visualizing Distances	5.4	5.5	6.1	ns
	79 %	86 %	100 %	
3. Visualizing Topography	5.4	5.3	5.5	ns
	86 %	79 %	93 %	
4. Memorizing Terrain	4.9	5.1	4.9	ns
	71 %	71 %	71 %	
5. Ease of Using Method	5.7	5.8	5.7	ns
	93 %	86 %	93 %	
6. Mental Effort Required	5.75	6	5.75	ns
	92 %	92 %	92 %	

[+] *Significant Effect: $p < 0.05$: Shaded areas indicate item rated acceptable by less than 80% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*

Exit questionnaire results for terrain visualization found no significant differences for:

- Creating mental image of the ground,
- Visualizing distances,
- Visualizing topography,
- Memorizing terrain,
- Ease of using method, and
- Mental effort required.

Less than 80% of soldiers rated the HMD and FIND system acceptable for creating a mental image of the ground. Less than 80% of soldiers rated the HMD acceptable for visualizing distances and less than 80% rated the FIND system acceptable for visualizing topography. Less than 80% of soldiers rated all modalities acceptable for memorizing terrain.

4.3.5 Exit Questionnaire Results: Route Planning

The results from the Exit Questionnaire regarding route planning are illustrated in Table 8 and discussed below.

Table 8: Exit Questionnaire results for route planning

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) $p < 0.05$
	HMD	FIND	Compass	Modality
1. Ease of Planning Route	6	6	5.8	ns
	93 %	86 %	93 %	
2. Awareness of Terrain Landmarks	5.5	5.4	5.8	ns
	93 %	79 %	100 %	
3. Learning Mission Features	5.9	5.6	5.8	ns
	93 %	86 %	93 %	

[+] *Significant Effect: $p < 0.05$: Shaded areas indicate item rated acceptable by less than 80% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*

The Exit Questionnaire results for route planning show no significant differences for, ease of planning route, awareness of terrain landmarks, and learning mission features. Less than 80% of soldiers rated the FIND system acceptable for awareness of terrain landmarks.

4.3.6 Terrain Visualization and Route Planning Summary

Low and inconsistent acceptance ratings in the Post-Mission and Exit Questionnaires indicated that some aspects of all the modalities were unacceptable to soldiers for terrain visualization and route planning. In terms of terrain visualization, performance measures indicated soldiers estimated the bearing to the objective significantly more accurately using the FIND system and HMD than using the compass modality. In the Post-Mission Questionnaire, the FIND and HMD modalities also attained significantly higher ratings than the compass modality with regard to awareness of waypoint locations. The FIND modality also attained significantly higher ratings than the HMD for terrain reconstruction.

While the FIND modality was found most acceptable for some aspects of terrain visualization, a number of problems were also identified. Less than 80% of soldiers rated the FIND system acceptable for completeness of terrain knowledge on the Pre-Mission Questionnaire. Less than 80% of soldiers rated the FIND and compass modalities acceptable for awareness of mission feature locations on the Post-Mission Questionnaire and less than 80% rated the FIND system acceptable for visualizing topography on the Exit Questionnaire. Also on the Exit Questionnaire, less than 80% of soldiers rated the HMD and FIND modalities acceptable for creating mental image of the ground and less than 80% of soldiers rated all modalities acceptable for memorizing terrain.

Additional problems were identified with the FIND modality regarding route planning. Less than 80% of soldiers rated the FIND system acceptable for effectiveness for route planning on the Pre-Mission Questionnaire and less than 80% of soldiers rated the FIND system acceptable for awareness of terrain landmarks on the Exit Questionnaire. A number of problems for route planning specific to the HMD were also identified. In the Pre-Mission Questionnaire, less than 80% of soldiers rated the HMD acceptable for accuracy of terrain knowledge. In the Post-Mission Questionnaire, less than 80% of soldiers rated the HMD acceptable for awareness of terrain layout and terrain reconstruction. On the Exit mission Questionnaire less than 80% of soldiers rated the HMD acceptable for visualizing distances.

4.4 Ease of Use

This section addresses issues of usability of the map modalities. This includes ease of learning, operating, and accessing information as well as interface design.

4.4.1 Post-Mission Questionnaire: Ease of Use

The results from the Post-Mission Questionnaire regarding ease of use are illustrated in Table 9 and discussed below.

Table 9: Post-Mission Questionnaire results for ease of use

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
1. Learning the System	6	6.1	6	ns
	93 %	86 %	93 %	
2. Operating the System	5.6	6	6.1	ns
	86 %	86 %	93 %	
3. Planning Route	5.9	5.9	6	ns
	86 %	93 %	93 %	
4. Navigating Terrain	5.7	6.1	5.4	ns
	93 %	79 %	71 %	
5. Ease of Estimating Distance	6.5	4.9	5.5	F < H
	86 %	64 %	86 %	
6. Time Pressure During Navigation	5.9	6.1	5.5	C < F
	86 %	93 %	79 %	
7. Ease of Estimating Locations	5.8	5.3	5.4	ns
	71 %	71 %	79 %	

[+] *Significant Effect: p < 0.05: Shaded areas indicate item rated acceptable by less than 80% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*

The Post-Mission Questionnaire results for ease of use indicate the HMD attained significantly higher acceptance ratings in comparison to the FIND modality with regard to the ease of estimating distance. Less than 80% of soldiers rated the FIND system acceptable for ease of estimating distance. The FIND modality was rated significantly more acceptable than the compass modality in terms of time pressure during navigation. Less than 80% of soldiers rated the compass modality acceptable in terms of time pressure during navigation.

Less than 80% of soldiers rated any of the systems acceptable for ease of estimating locations. This is inconsistent with performance measures for error estimating bearing because soldiers were significantly more accurate estimating bearings using the HMD and FIND systems than soldiers using the compass. In terms of ease of navigating terrain, the compass and FIND modalities were rated acceptable by less than 80% of soldiers. No significant differences were found for:

- Learning the system,
- Operating the system,
- Planning route,
- Navigating terrain, and
- Ease of estimating locations.

4.5 Evaluation of System

This section addresses issues of confidence, workload, tactical feasibility and the overall impression of the system.

4.5.1 NASA TLX: Workload Questionnaire

Participants completed a NASA TLX workload questionnaire to assess the workload related to the use of the different modalities. The results from the NASA TLX workload questionnaire have been illustrated in Table 10 and discussed below. Based on a ten-point scale, a higher score corresponds to increased workload.

Table 10: NASA TLX Questionnaire results for mental workload

	Mean acceptability rating and % of participants giving acceptability rating of at least 5 out of 10			Significant Difference(s)[+] p < 0.05
	HMD	FIND	Compass	Modality
1. Mental Demand	3.1 ±1.93	3.3 ±1.53	5.2 ±2.58	F, H < C
	79 %	85 %	57 %	
2. Physical Demand	3.9 ±1.95	3.1 ±1.92	3.9 ±1.95	ns
	86 %	71 %	71 %	
3. Temporal Demand	3.7 ±2.95	3 ±4.40	4.6 ±3.66	F < C
	79 %	86 %	57 %	
4. Performance	3.9 ±2.44	3.1 ±2.30	5 ±2.73	ns
	79 %	64 %	50 %	
5. Effort	3.1 ±1.79	3.6 ±2.01	4.9 ±1.90	F < C
	86 %	79 %	36 %	
6. Frustration	5 ±2.37	4.7 ±2.97	4.75 ±2.23	ns
	57 %	50 %	50 %	

[+] *Significant Effect: p < 0.05: Shaded areas indicate item rated demanding by more than 20% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass*

The NASA TLX Questionnaire results for mental workload indicate soldiers rated the FIND system significantly more acceptable than the compass in terms of temporal demand. In fact, less than 80% of soldiers rated the compass acceptable for this item. The compass required more time to use because soldiers had to find their bearing and manually orient the map North using the compass. Soldiers were also required to stop or slow their pace to look at the map. In contrast, the FIND system could be used on demand while walking and did not require orientation.

While the FIND and HMD attained significantly lower workload ratings compared to the compass for mental demand, less than 80% of soldiers rated the FIND and compass acceptable for this item. Less than 80% of soldiers rated the FIND, HMD, and compass acceptable in terms of performance and frustration. The high frustration level might be indicative of general task difficulty. Further, the FIND system received significantly lower workload ratings for effort than the compass. Less than 80% of soldiers rated both the HMD and compass acceptable in terms of effort.

In general, these poor workload ratings may reflect usability problems in terms of using the compass modality for carrying out the tasks in this study.

4.5.2 Pre-Mission Questionnaire Ratings: Mental Workload

The results from the Pre-Mission Questionnaire regarding mental workload are illustrated in Table 11 and discussed below.

Table 11: Pre-Mission Questionnaire results for mental workload

	Mean performance rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) p < 0.05
	HMD	FIND	Compass	Modality
1. Time Pressure During Visualization	5.3	5.1	5.4	ns
	79 %	64 %	86 %	
2. Complexity of Information	5.8	5.6	5.9	ns
	86 %	86 %	93 %	
3. Ease of Interpreting Information	5.7	5.4	5.9	ns
	93 %	79 %	93 %	
4. Ease of Creating Mental Image of Terrain	5.3	5.1	5.1	ns
	79 %	64 %	71 %	
5. Ease of Estimating Distances	5.6	5.1	5.3	ns
	71 %	64 %	79 %	

Shaded areas indicate item rated acceptable by less than 80% of soldiers. ns = not significant

There were no significant differences among modalities. However, Pre-Mission Questionnaire results for mental workload indicate that less than 80% of soldiers rated the HMD and FIND modalities acceptable for time pressure during visualization. The FIND modality was rated acceptable by less than 80% of soldiers for ease of interpreting information. Less than 80% of soldiers rated any of the modalities acceptable for ease of creating mental image of terrain and for ease of estimating distances.

4.5.3 Pre-Mission Questionnaire Ratings: Overall Acceptability

The results from the Pre-Mission Questionnaire regarding overall acceptability are illustrated in Table 12 and discussed below.

Table 12: Pre-Mission Questionnaire results for overall acceptability

	Mean Performance and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) $p < 0.05$
	HMD	FIND	Compass	Modality
1. Contribution to Terrain Awareness	5.4	5.3	5.6	ns
	79 %	71 %	86 %	
2. Ease of Acquiring Visualization Knowledge	5.4	5.4	5.4	ns
	71 %	71 %	86 %	
3. Mental Workload to Use Knowledge	5.6	5.3	5.8	ns
	79 %	77 %	93 %	
4. Time Required to Use Method	5.6	5.3	5.6	ns
	71 %	79 %	79 %	
5. Ease of Using Method	5.6	5.3	5.6	ns
	71 %	79 %	79 %	
6. Confidence in Visualization Knowledge	5.6	5.4	5.6	ns
	71 %	86 %	86 %	
Overall Acceptability of Method	5.7	5.6	5.7	ns
	77 %	85 %	93 %	

[+] *Significant Effect: $p < 0.05$: Shaded areas indicate item rated demanding by more than 20% of soldiers. F = FIND System, H = Helmet Mounted Display, C = Compass, ns = not significant*

There were no significant differences among modalities. Pre-Mission Questionnaire ratings for overall acceptability did, however, indicate less than 80% of soldiers rated any of the modalities acceptable for ease of use and for time required. The FIND and HMD modalities were rated acceptable by less than 80% of soldiers for contribution to terrain awareness, ease of acquiring visualization knowledge, and mental workload to use knowledge. This might be a result of the maps displayed on the Land Warrior system, which do not include gridlines. We assume gridlines were not included with the digital map to discourage them from estimating distances with the naked eye and to force soldiers to use the measurement tool. The HMD modality was rated acceptable by less than 80% of soldiers for confidence in visualization knowledge and overall acceptability of method.

4.5.4 Post-Mission Questionnaire Ratings: Overall Acceptability

The results from the Post-Mission Questionnaire regarding overall acceptability are illustrated in Table 13 and discussed below.

Table 13: Post-Mission Questionnaire results for overall acceptability

	Mean acceptability rating and % of participants giving acceptability rating of at least 4 out of 7			Significant Difference(s) p < 0.05
	HMD	FIND	Compass	Modality
1. Effectiveness for Route Planning	5.8	5.9	5.9	ns
	86 %	93 %	93 %	
2. Contribution to Navigation Performance	6.1	6.1	5.6	ns
	93 %	93 %	79 %	
3. Mental Workload	6.1	5.8	5.4	ns
	93 %	79 %	86 %	
4. Tactical Feasibility	5.6	5	5.9	ns
	79 %	50 %	86 %	
5. Confidence in System	5.4	5.5	5.8	ns
	79 %	77 %	86 %	
Overall Acceptability of Method	5.6	5.7	5.6	ns
	93 %	86 %	93 %	

Shaded areas indicate item rated acceptable by less than 80% of soldiers. ns = not significant

There were no significant differences among modalities. Post-Mission Questionnaire ratings for overall acceptability indicate less than 80% of soldiers rated the compass modality acceptable for contribution to navigation performance. Less than 80% of soldiers rated the FIND and HMD modalities acceptable in terms of tactical feasibility and confidence in system.

Soldiers rated each system acceptable in terms of confidence in the system, indicating a trust in technology that was not supported by performance data in terms of the ability to navigate around a hazard, total distance traveled, or time to traverse ground.

4.5.5 Exit Questionnaire Results: Overall Acceptability

The results from the Post-Mission Questionnaire regarding overall acceptability are illustrated in Table 14 and discussed below.

Table 14: Exit Questionnaire results for overall acceptability

	Overall Acceptability Means			Significant Difference(s) $p < 0.05$
	% of participants giving acceptability rating of at least 4 out of 7			
	HMD	FIND	Compass	Modality
Overall Acceptability of Method	5.7	6	5.2	C < F
	86 %	93 %	93 %	

[+] *Significant Effect: $p < 0.05$: F = FIND System, H = Helmet Mounted Display, C = Compass*

The Exit Questionnaire results for overall acceptability indicate the FIND modality was rated significantly more acceptable than the compass modality in terms of acceptability of method.

4.5.6 Evaluation of System Summary

In general, the FIND modality outperformed the HMD and compass. While results of the Post-Mission Questionnaire for overall acceptability of method indicated no significant difference between the modalities, results of the Exit Questionnaire indicated the FIND modality was rated significantly more acceptable overall than the compass.

In terms of ease of use, the low acceptance ratings and variability in the results highlight a variety of problems with all the modalities. For example, less than 80% of soldiers rated any of the systems acceptable for ease of estimating locations on the Pre-Mission Questionnaire. Less than 80% of soldiers rated any of the modalities acceptable in terms of performance and frustration on the Workload Questionnaire, and less than 80% of soldiers rated any of the modalities acceptable for ease of using method on the Post-Mission Questionnaire.

Overall results of the NASA TLX workload scale indicated soldiers rated the FIND system more acceptable than the compass. The FIND system received significantly better workload ratings for effort than the compass. Less than 80% of soldiers rated both the HMD and compass acceptable in terms of effort. With regard to temporal demand, the FIND modality outperformed the compass. Less than 80% of soldiers rated the compass acceptable for temporal demand. This is consistent with the Pre-Mission Questionnaire where the FIND modality was rated significantly more acceptable than the compass modality in terms of time pressure during navigation. However, results of the Post-Mission Questionnaire indicated that less than 80% of soldiers rated any of the modalities acceptable for time required for using method.

In terms of terrain knowledge, the compass modality outperformed the FIND and HMD. The FIND and HMD modalities were rated acceptable by less than 80% of soldiers for mental workload to use knowledge and for contribution to terrain awareness on the Exit Questionnaire.

The HMD modality was rated acceptable for confidence in visualization knowledge by less than 80% of soldiers.

While the FIND modality appeared to perform best overall, several usability issues were identified with the FIND modality. On the Pre-Mission Questionnaire, the HMD attained significantly higher acceptance ratings than the FIND modality with regard to the ease of estimating distance. The FIND modality was rated acceptable by less than 80% of soldiers on this item. In terms of ease of navigating terrain, the compass and FIND modalities were rated acceptable by less than 80% of soldiers on the Pre-Mission Questionnaire. For mental demand, less than 80% of soldiers rated the FIND and compass acceptable on the Workload Questionnaire. For ease of acquiring visualization knowledge, the FIND and HMD modalities were rated acceptable by less than 80% of soldiers on the Exit Questionnaire.

5 Discussion

This section provides a discussion of the results with respect to the acceptance ratings, likes and dislikes of the system, possible improvements to support soldier information requirements, and design recommendations for consideration in the next series of experiments.

5.1 User Acceptance

User acceptance ratings for a majority of the criteria indicated that the FIND and HMD modalities were rated more acceptable by soldiers than the compass. Exit Questionnaire ratings for overall acceptability indicated that the FIND modality attained significantly higher ratings than the compass. These results are discussed below with regard to the likes and dislikes expressed by soldiers, corresponding to the statistical differences in the attained results. Discussions focus on each experimental condition. A proposed task-based navigation solution is also described.

5.1.1 Digital Map With Audio Wayfinding Aid

Combining a digital map display (tablet) with an auditory wayfinding aid (FIND) was more often the highest rated modality across the questionnaires and performance measures. The FIND modality attained significantly higher ratings than the compass on the Exit Questionnaire for overall acceptability of method. Soldiers stated that the FIND modality was very accurate for navigation purposes, and it was easy to maintain the correct heading while using the system. The FIND modality was rated significantly more acceptable than the compass for ease of navigating route. Results of the Workload Questionnaire also indicated the FIND modality was rated significantly less demanding than the compass for effort. Soldiers indicated it was easy to understand, easy to use to stay on route, and easy to find waypoints using the system. As one soldier stated, "I found FIND better than Land Warrior in terms of keeping on line as you go." Supporting these comments, the FIND modality performed significantly better than the compass modality on performance measures for mean RMS error for waypoints 1-4, and the FIND modality attained significantly higher ratings than the HMD for determining direction to waypoint. In addition, FIND was the only modality rated acceptable for use while moving on the Post-Mission Questionnaire by more than 80% of soldiers. According to soldiers it was not necessary to count paces with the audio FIND. Soldiers said, "You can run with the FIND system. Just run, listen, and go."

During the focus group, soldiers stated they found the audio FIND faster for navigation than the other modalities. This is supported by results of the Post-Mission Questionnaire where the FIND modality was rated significantly more acceptable than the compass for time pressure during navigation and results of the Workload Questionnaire where the FIND modality was rated significantly less demanding than the compass for temporal demand. Soldiers preferred the touch screen interface used with tablet to the mouse used with the HMD. Soldiers commented the tablet touch screen is easier, faster, and more accurate than the mouse used with the HMD. Soldiers also indicated they liked the tablet display size compared to the HMD. According to soldiers, "If everyone had a HMD it would be difficult for the section commander to show his screen to his troops. With a tablet the section commander can show his screen to everyone."

Despite being strongly supported by questionnaire and performance results for navigation, several problems were identified with the FIND modality with regard to terrain visualization and route planning. The tablet digital map was uniquely rated acceptable by less than 80% of soldiers on the Pre-Mission Questionnaire for route planning, completeness of terrain knowledge, and ease of interpreting information. While the tablet with audio FIND was rated significantly more acceptable than the digital map alone on the Post-Mission Questionnaire for terrain reconstruction, it was uniquely rated acceptable by less than 80% of soldiers on the Exit Questionnaire for visualizing topography and awareness of terrain landmarks. Many of these concerns can be ascribed directly to the tablet technology used in the experiment (i.e. poor daylight readability) and not to the concept of a tablet per se.

Soldiers using the tablet with audio FIND stated that sometimes they did not know where they were on the map. Soldiers said that due to technology problems, the Land Warrior system did not always accurately update and show their correct location. This comment was supported by the Post-Mission Questionnaire where less than 80% of soldiers rated the FIND modality acceptable for ease of estimating distance and mental workload. Some soldiers indicated the tablet was too heavy and they would prefer to carry a paper map instead. Further, soldiers stated the physical size of the tablet was too large to be used by riflemen. Some soldiers indicated a smaller PDA-sized tablet would be more appropriate. Another problem with the tablet involved orienting the system to the ground. While the map used a fixed North-up orientation, the North indicator was absent on the Land Warrior display. Soldiers indicated they would prefer if the tablet map display automatically rotated to align the map to their facing direction.

5.1.2 Digital Map Alone (Head Mounted Display)

In general, the HMD was rated superior to the compass but it was not rated as acceptable as the FIND modality. The only item where the HMD was rated more acceptable than the FIND modality was ease of estimating distance. This rating for ease of estimating distances on the map was supported by the performance measures for error estimating bearing to mission objectives where the FIND and HMD modalities were significantly more accurate than the compass modality. This performance rating may be attributed to the Land Warrior measurement tool that enabled soldiers using the HMD to precisely measure the distance and bearing between any two points on the map. Although some soldiers said they did not need this tool and would prefer to use gridlines for measuring distances by the conventional means, they agreed that providing distance and bearing was useful as another point of reference. When asked what they thought of the measurement tool, some soldiers said, “You can’t beat it. It is good to have a tool where you can pick any two points to calculate distances like gaps and minefields. Point to point is phenomenal.” Consistent with these comments, the FIND and HMD modalities were rated significantly lower in terms of mental demand than the compass on the Workload Questionnaire.

With regard to navigation, the HMD was rated superior to the compass modality. Results of performance measures indicate the FIND and HMD modalities were significantly more accurate than the compass modality in terms of distance to endpoint for waypoints 1 to 4 and distance to waypoint 4 alone. Consistent with this, the FIND and HMD modalities were rated significantly more acceptable than the compass on the Post-Mission Questionnaire for awareness of own location, awareness of waypoint locations, finding next waypoint after hazard, and determining when waypoint is reached. The FIND and HMD modalities were also rated significantly more

acceptable than the compass for navigating around unforeseen hazard and accuracy for locating waypoints.

However, navigation problems relating to speed, perception, and orientation prevented the HMD from outperforming the FIND modality. In terms of speed, soldiers commented that the position and the heading of the chevron did not update frequently enough. While soldiers stated that the HMD was useful for keeping a good line, soldiers found waiting for the chevron to update (euphemistically called, "combat patience") infuriating. Soldiers said, "Just when you had decided what direction to go, the chevron on the map display jumped and made you second guess yourself." Also zooming in and out on the map required a great deal of time to redraw the screen. Soldiers commented that using the system was not tactical because it would not be realistic to wait for the chevron to update when on a patrol. A 10-20 second delay can mean the difference between safely moving on your route toward the RV or being caught in enemy line of fire.

In terms of orientation problems, fewer soldiers rated the HMD modality acceptable than rated the FIND modality acceptable on the Post-Mission Questionnaire for use while stationary. The Land Warrior had to be in motion to determine the direction the soldier was moving because it used differential GPS signals to estimate the course of travel. Differential GPS involves the cooperation of two receivers, one that is stationary and another that is roving around making position measurements. Therefore the chevron pointer did not always accurately indicate the soldier's heading when the soldier was standing still. Consistent with this issue, the FIND modality was rated significantly more acceptable than the HMD for determining direction to waypoint and terrain reconstruction. In terms of perceptual problems, fewer soldiers rated the HMD modality acceptable than the FIND for use while moving on the Post-Mission Questionnaire. Soldiers reported experiencing perceptual problems while looking into the HMD that interfered with their ability to walk.

Less than 80% of soldiers rated the HMD acceptable for overall acceptability of method on the Post-Mission Questionnaire. This may be due to the difficulty orienting the map displayed on the HMD to the ground. The permanent north-up orientation of the map display created a number of problems. To orient their map to the ground, soldiers were required to first orient their tablet to align the top of the screen to north. This was difficult on the move and resulted in soldiers making grosser estimations of line rather than stopping and going through the orientation drill. This problem was exacerbated when the soldier was traveling in any southerly direction; when traveling south the map was effectively reversed to its true north-up orientation. Soldiers were more prone to map reversal errors where a quick glance at the map display suggested that they needed to move left to link up with their route line when in fact, due to the map being reversed, they actually needed to move right. In many instances of HMD use, soldiers would walk in large circles because of map reversal confusion.

A number of items relating to terrain visualization were rated acceptable by less than 80% of soldiers uniquely for the HMD. These included:

- Use while stationary;
- Determining direction to waypoint;
- Terrain recognition;
- Accuracy of terrain knowledge;

- Awareness of terrain layout;
- Terrain reconstruction;
- Visualizing distances; and
- Confidence in visualization knowledge.

5.1.3 Paper Map and Compass

Overall, the compass was rated significantly less acceptable than the FIND modality. All significant differences between the compass and FIND or HMD favoured the FIND or HMD. The compass did not receive a significantly higher mean acceptance rating for any of the performance measures or questionnaire items. However, according to soldiers' statements, carrying a map and compass was a fundamental safety requirement. Soldiers stated that they "wouldn't trust the (Land Warrior) system for straight navigation without carrying a paper map as a safety blanket". Soldiers indicated they like the gridlines, topographic lines, and man-made obstacles marked on the paper map. A paper map with gridlines was strongly preferred over the Land Warrior, which provided grid coordinates for the cursor position. Soldiers explained, "We prefer a grid (gridlines) because if you get a call for a suspected enemy, with Land Warrior you need to troll around with the mouse until you find the location".

While the compass modality received favourable comments, especially in terms of simplicity, dependability, and reliability, there were a number of usability issues associated with the paper map. A number of items relating to situation awareness were rated acceptable by less than 80% of soldiers uniquely for the compass modality. These included:

- Awareness of own location;
- Determining when waypoint is reached;
- Ease of finding next waypoint after hazard;
- Accuracy for locating waypoints; and
- Contribution to navigation performance.

The most significant problem with the compass was the inability of soldiers to determine when they had reached the waypoint. Soldiers were required to use terrain landmarks and distance estimates to determine when the waypoint was reached. Performance measures for distance to endpoint indicated soldiers were nearly ten times less accurate finding waypoints using the compass modality than using the FIND modality. Further, soldiers performed significantly worse using the compass than using the other modalities in terms of RMS error for waypoints and for error estimating bearing to objectives. Consistent with these findings, participants rated the compass significantly less acceptable than either of the two other modalities for:

- Awareness of waypoint locations;
- Determining when waypoint is reached;
- Ease of finding next waypoint after hazard;
- Accuracy for locating waypoints;

- Awareness of own location;
- Navigating around unforeseen hazard; and
- Mental demand.

Soldiers using the compass modality were the slowest to complete the navigation task. Comparison of the mean times for total time for waypoints 1 to 4 and time from waypoints 3 to 4 showed soldiers using the compass required more time to navigate the route than soldiers using the FIND or HMD modalities. This is supported by low soldier acceptance ratings, where the compass was uniquely rated acceptable by less than 80% of soldiers for speed of terrain traverse, time pressure during navigation, and temporal demand.

5.1.4 Proposed Task-Based Navigation Solution

A typical navigation mission breaks down into several functional phases. The Pre-Mission phase includes navigation and mission planning as well as mission briefings to soldiers. The mission execution phase includes terrain awareness, route wayfinding, in-situ modifications to mission plans, and battlefield awareness. The Post-Mission phase is not relevant here. Within these phases, task responsibilities are typically divided between the leadership role (i.e. Section Comd or 2IC) and the rifleman role. Leadership tasks tend to require terrain awareness and battlefield awareness for mission planning and decision-making. Riflemen tasks tend to focus on mission execution (i.e. route wayfinding, local surveillance, and target detection and engagement). The information requirements associated with these tasks also tend to split along leadership and riflemen lines. Leadership roles tend to require more survey knowledge of the terrain and battle situation while riflemen roles tend to require more route knowledge to support wayfinding.

The results of this study would suggest that the leadership role would benefit most from a detailed digital map to provide the necessary survey knowledge with an accurate, current updating capability for own location and a rotating map which automatically orients to the user's facing direction. While this information could be provided in an HMD format, many soldiers indicated that a tablet would be more suitable for mission planning, consulting and sharing map information with others as well as for briefing other soldiers on the mission.

Riflemen also benefit from the terrain and situation awareness information afforded by local survey knowledge but the requirement for survey insight is less frequent and less detailed. Our results suggest that the riflemen would benefit most from a tool which provides route knowledge support in a way that does not distract the user from their surveillance and target detection tasks, can be used on the move, and provides wayfinding cues with the minimum amount of information. While this information could be provided in an HMD format, a visual modality may distract from performance in other visually demanding tasks. For this reason the FIND auditory or tactual modalities may offer the most promising solution.

5.2 Future Research

Based on the results of this study, the following areas of future research are recommended to further define the information requirements of dismounted infantrymen for wayfinding. Soldier comments with regards to possible improvements are included where applicable.

5.2.1 Investigate Effect of Directional Information on Wayfinding Performance

The audio FIND system provided directional information to the auditory channel. Since the task environment where soldiers will use the system may demand full use of the soldier's auditory channel, other modalities must be evaluated. Alternative ways to effectively present directional information for wayfinding should be investigated. This may involve presenting directional arrows on the visual display or other types of directional cues.

The Land Warrior system used differential GPS calculations to determine what heading to display on the map. Soldiers said they would prefer a continuous update on the digital map to indicate their current heading. A digital compass could be used to generate the continuous heading data. During the focus group, the question of a rotating map versus a rotating chevron was discussed. Soldiers indicated that a rotating map would be preferred if it were able to update quickly and smoothly. Investigation will be required to evaluate the usability of a rotating map in a future study.

5.2.2 Improve Navigational Displays

The following navigational display attributes should be improved based on the soldier's performance, ratings, and comments. Soldiers commented that a dot is more appropriate than a chevron for indicating their position on the map. According to soldiers, due to the size of the chevron, it was difficult to know when they had reached the waypoint by looking at the digital map. Determining the appropriate size, shape, and colour of the position indicator on the map display will require further investigation. Although the audio FIND system provided a cue to indicate when soldiers were within 20 meters of the waypoint, soldiers requested a confirmation when the waypoint was reached. Investigation is required to determine how best to provide a confirmation when the waypoint is reached.

Soldiers indicated it would be useful to display the chevron on a route line to show their distance to the best line. Investigation is required to evaluate the usability of a route line between waypoints and a snail trail showing the path soldiers have walked. The topic of displaying and hiding layers of map information was also discussed during the focus group (e.g. enemy layer, friendly layer, etc.). Soldiers indicated that the layers could be used to filter the display by mission (e.g. show phase lines, show barrier trace, show route plan, etc.) or by rank (e.g. show SC, show section, show assault groups, etc.). Further investigation will be required to determine the appropriateness of using layers, what information to group by layer, and how soldiers will interact with the system to show and hide layers.

5.2.3 Improve Map Zoom

Soldiers reported that objects displayed on the Land Warrior obscured map features because they did not resize when the map is zoomed out. Investigation is required with regard to whether or not to resize the icons when the map resizes, what zoom levels are required, and how many steps to provide.

5.2.4 Improve the Speed and Accuracy of the GPS

According to soldiers, Land Warrior did not update the position of the chevron frequently enough. The GPS used with Land Warrior sampled approximately once every 10-20 seconds. Soldiers indicated they required much more frequent updates. Investigation is required to determine how frequently the GPS should update the display. The system should raise an alarm to warn soldiers if GPS dropouts occur (e.g. warn the soldier if the chevron fails to update). For example, the GPS position indicator on Delorme 3D Topoquads turns from "green" to "red" if the GPS fails to send a signal.

5.2.5 Investigate Improvements to Hazard Avoidance

Investigation is required to provide a better means of helping soldiers avoid navigation hazards. All three systems tested in this study failed to help the soldiers to safely avoid the minefields. For example, the system could automatically recommend a route around the perimeter of a hazard if soldiers enter the coordinate and size of the hazard. Soldiers indicated they would prefer to plot a hazard on the map rather than plan a route around a hazard. One soldier commented that at one point the Land Warrior display updated and he appeared directly over the minefield. Soldiers suggested some type of warning should be raised by the system when they were within a pre-determined, safe distance of any hazard.

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ANNEX A:
Personal Information

PERSONAL INFORMATION

Please provide the requested information in the spaces provided:

Name	Service Number	MOC

5.2.5.1.1 Rank	Gender
Pte ○ Cpl ○ MCpl ○ Sgt ○	Male ○ Female ○

Length of Service (Regular and Reserve)			
None ○	1 - 5 Years ○	5 - 10 Years ○	Over 10 Years ○

Operational Experience (check more than one theatre if appropriate)						
Middle East ○	Golan Heights ○	Sinai ○	Croatia ○	Bosnia ○	Rwanda ○	Cyprus ○
Somalia ○	Cambodia ○	Haiti ○	Kosovo ○	Other:		

Age (years)																		
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	>35
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

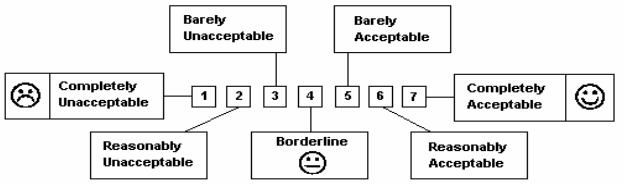
Skills
Please rate your map reading skills ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent
Please rate your route planning skills ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent
Please rate your navigation skills ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent
Please rate your compass skills ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent
Please rate your pace count skills ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent
Please rate your sense of direction ○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent

Experience			
Please rate your training and/or operational experience with patrol route planning.			
○ None	○ Some	○ Moderate	○ Extensive
Please rate your training and/or operational experience using the compass/pace count method.			
○ None	○ Some	○ Moderate	○ Extensive
Please rate your training and/or operational experience using a PLGR (GPS).			
○ None	○ Some	○ Moderate	○ Extensive
Please rate your training and/or operational experience using topographical maps.			
○ None	○ Some	○ Moderate	○ Extensive
Please rate your training and/or operational experience using NVGs.			
○ None	○ Some	○ Moderate	○ Extensive
Please rate your training and/or operational experience in patrolling and navigation operations.			
○ None	○ Some	○ Moderate	○ Extensive

ANNEX B:
Pre-Mission Questionnaire

Participant ID#: _____ _____ DATE:_____

Visualization Method:
- 2D Map / Compass ○
- 2D HMD / Compass ○
- 2D Tablet / FIND ○



Session: 1 ○ 2 ○ 3 ○

Route: 1 ○ 2 ○ 3 ○

	Acceptability						
	☹ 1	2	3	😐 4	5	6	☺ 7
Effectiveness of Method for:							
Route Planning	○	○	○	○	○	○	○
Awareness of Terrain Layout	○	○	○	○	○	○	○
Accuracy of Terrain Knowledge	○	○	○	○	○	○	○
Completeness of Terrain Knowledge	○	○	○	○	○	○	○
Awareness of Mission Features	○	○	○	○	○	○	○
Confidence in Method for:							
Planning Route	○	○	○	○	○	○	○
Navigating Terrain	○	○	○	○	○	○	○
Mental Workload of Method:							
Time Pressure During Visualization	○	○	○	○	○	○	○
Complexity of Information	○	○	○	○	○	○	○
Ease of Interpreting Information	○	○	○	○	○	○	○
Ease of Creating Mental Image of Terrain	○	○	○	○	○	○	○
Ease of Estimating Distances	○	○	○	○	○	○	○

	Acceptability						
	☹ 1	2	3	😐 4	5	6	☺ 7
Generally:							
Contribution to Terrain Awareness	○	○	○	○	○	○	○
Ease of Acquiring Visualization Knowledge	○	○	○	○	○	○	○
Mental Workload to Use Knowledge	○	○	○	○	○	○	○
Time Required to Use Method	○	○	○	○	○	○	○
Ease of Using Method	○	○	○	○	○	○	○
Confidence in Visualization Knowledge	○	○	○	○	○	○	○
OVERALL ACCEPTABILITY OF METHOD	○	○	○	○	○	○	○

Likes Dislikes

Indicate the features/information you liked the most.	Indicate the features/information you liked the least.

Improvements

How would you improve this visualization method?

Additional Comments

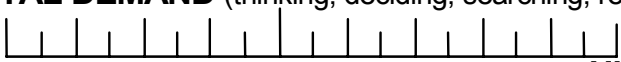
ANNEX C:
Workload NASA TLX Questionnaire

NAME : _____

DISPLAY: Compass ☐ Visual ☐ Auditory ☐ Tactile ☐

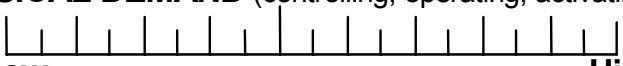
Section A: Rate the trial by marking each scale at the point which matches your experience. Each line has two endpoint descriptors to help describe the scale. Please consider your responses to these scales carefully.

MENTAL DEMAND (thinking, deciding, searching, remembering)



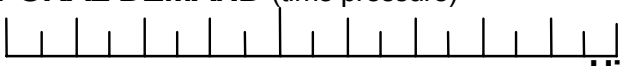
Low (easy, simple) **High** (demanding, complex)

PHYSICAL DEMAND (controlling, operating, activating)



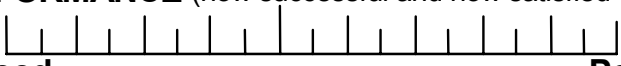
Low (easy, restful) **High** (demanding, laborious)

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)**

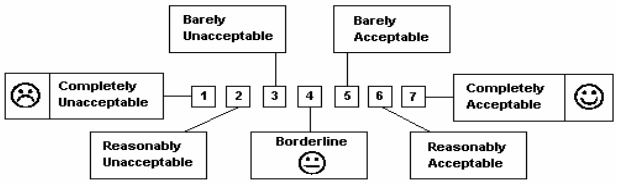
ANNEX D:
Post-Mission Questionnaire

Participant ID#: _____ DATE:_____

Visualization Method:
- 2D Map / Compass ○
- 2D HMD / Compass ○
- 2D Tablet / FIND ○

Session: 1 ○ 2 ○ 3 ○

Route: 1 ○ 2 ○ 3 ○



	Acceptability						
	☹ 1	2	3	😐 4	5	6	☺ 7
Effectiveness of Method for:							
Awareness of Terrain Layout	○	○	○	○	○	○	○
Awareness of Own Location	○	○	○	○	○	○	○
Terrain Reconstruction (accuracy)	○	○	○	○	○	○	○
Awareness of Mission Feature Locations	○	○	○	○	○	○	○
Awareness of Waypoint Locations	○	○	○	○	○	○	○
Ease of Use for:							
Learning the System	○	○	○	○	○	○	○
Operating the System	○	○	○	○	○	○	○
Planning Route	○	○	○	○	○	○	○
Navigating Terrain	○	○	○	○	○	○	○
Ease of Estimating Distance	○	○	○	○	○	○	○
Time Pressure during Navigation	○	○	○	○	○	○	○
Ease of Estimating Locations	○	○	○	○	○	○	○

	Acceptability						
	☹ 1	2	3	😐 4	5	6	☺ 7
Wayfinding Effectiveness:							
Use while moving	○	○	○	○	○	○	○
Use while stationary	○	○	○	○	○	○	○
Speed of Terrain Traverse	○	○	○	○	○	○	○
Ease of Relating Terrain to Visualization Method	○	○	○	○	○	○	○
Determining Direction to next Waypoint	○	○	○	○	○	○	○
Determining when Waypoint is Reached	○	○	○	○	○	○	○
Navigating around Hazard	○	○	○	○	○	○	○
Ease of Finding Next Waypoint after Hazard	○	○	○	○	○	○	○
Amount of Information Presented	○	○	○	○	○	○	○
Accuracy of Information Presented	○	○	○	○	○	○	○
Generally:							
Effectiveness for Route Planning	○	○	○	○	○	○	○
Contribution to Navigation Performance	○	○	○	○	○	○	○
Mental Workload	○	○	○	○	○	○	○
Tactical Feasibility	○	○	○	○	○	○	○
Confidence in System	○	○	○	○	○	○	○
OVERALL ACCEPTABILITY OF METHOD	○	○	○	○	○	○	○

Likes Dislikes

Indicate the features/information you liked the most.	Indicate the features/information you liked the least.

Improvements

How would you improve this method?

Additional Comments

ANNEX E:
Exit Questionnaire

Participant ID#: _____ **DATE:_____**

	2D Map / Compass	2D HMD / Compass	2D Tablet / FIND
Effectiveness for Terrain Visualization:	☹ 1 2 3 😐 4 5 6 ☺ 7	☹ 1 2 3 😐 4 5 6 ☺ 7	☹ 1 2 3 😐 4 5 6 ☺ 7
Creating Mental Image of the Ground	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Visualizing Distances	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Visualizing Topography	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Memorizing Terrain	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of Using Method	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Mental Effort Required	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Route Planning:			
Ease of Planning Route	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Awareness of Terrain Landmarks	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Learning Mission Features	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

	2D Map / Compass	2D HMD / Compass	2D Tablet / FIND
Effectiveness for Navigation:	☹ 1 2 3 😐 4 5 6 ☺ 7	☹ 1 2 3 😐 4 5 6 ☺ 7	☹ 1 2 3 😐 4 5 6 ☺ 7
Ease of Navigating Route	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Awareness of Own Location	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Awareness of Mission Features	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Accuracy of Method for Real Terrain Layout	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Accuracy of Method for Real Distances	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Navigating around Unforeseen Hazard	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Ease of Relating Method to the Ground	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Terrain Recognition	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Maintaining Orientation on the Ground	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Accuracy for Locating Waypoints	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
Confidence in System	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○
OVERALL ACCEPTABILITY OF METHOD	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○	○ ○ ○ ○ ○ ○ ○

Additional Comments

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(U) There has been little research comparing the utility and usability of digital map models and digital wayfinding aids to other traditional terrain navigation tools for small−scale navigation at the small unit and individual soldier level. For this reason, this experiment investigated two visualization methods that contribute mostly to survey knowledge (i.e. digital versus paper map information) and two wayfinding methods that contribute mostly to route knowledge (i.e. digital wayfinding system versus compass). This experiment compared three combinations of survey and route knowledge support: a digital map with a directional icon displayed on a head−mounted display (HMD), a digital map displayed on a tablet with a digital audio wayfinding aid (Future Infantry Navigating Device or FIND), and a paper topographic map with a compass.

Results indicated the digital map displayed on a tablet with a digital audio wayfinding aid (FIND) was most frequently the highest rated modality across the questionnaires, and produced the best performance outcomes. The FIND modality attained significantly higher ratings than the paper map for awareness of own location, awareness of waypoint locations, ability to find the next waypoint after avoiding a hazard, determining when a waypoint has been reached, and was found to be very accurate for navigation purposes. The FIND modality was rated significantly more acceptable than the paper map and compass for ease of navigating a route, and generated superior performance for minimizing track deviation from the assigned route. The FIND modality also attained significantly higher ratings than the digital map alone (HMD) for determining direction to waypoint.

These results support the use of a digital map tablet for small unit commanders for use during route planning, mission briefings, and battlefield awareness during mission execution. A digital wayfinding aid (e.g. FIND) is supported for the rifleman tasked with the role of navigator or wayfinder, where the emphasis is reaching planned waypoints accurately while still making the best tactical use of the immediate ground and observing arcs for possible enemy forces.

Several important issues were identified with the use of digital maps that can affect their utility in the field. These issues are discussed and future research issues are described.

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(U) Soldier Information Requirements Technology Demonstration Project; SIREQ TD; digital map; wayfinding

Navigation; Terrain Navigation; head−mounted display; HMD; Future Infantry Navigating Device; FIND; map and compass; digital audio wayfinding