ARMY RESEARCH LABORATORY

A Comparison of Soldier Performance Using Current Land Navigation Equipment With Information Integrated on a Helmet-Mounted Display

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Abstract

The report describes a field study designed to measure soldier performance of land navigation and other mission tasks using current navigational equipment and to compare these data with performance using navigational information integrated on a helmet-mounted display (HMD). Measures of stress, cognitive performance, and workload were also obtained. The results indicated that the soldiers traveled less distance between waypoints and experienced lower levels of mental workload using information presented on the HMD than they did using current navigational equipment. As might be expected, differences in time between manual and automatic map updates were significant, but no differences were found between current equipment and the HMD condition in object detection, determination of magnetic azimuth, or call for fire tasks. Differences between conditions in levels of stress and cognitive performance were not significant.

ACKNOWLEDGMENTS

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Thanks to those at the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory, particularly Jack Waugh for his assistance in defining the paths and object positions, to Mike Kosinski for the construction of the protractors with which our soldiers so accurately plotted coordinates, and to Dennis Hash and Nickey Keenan for their support in all phases and facets of this investigation. We would also like to express our appreciation to SFC Bobby King who assisted as pilot subject, trainer, and lane walker, and to SSG Brian James for the valuable extra set of hands he provided during training and testing.

Last but never least, we are particularly grateful to the soldiers who participated in this investigation. We thank them for their enthusiasm, dedication, and opinions, and particularly their patience and sense of humor.

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EXECUTIVE SUMMARY

This report presents the results of the first in a series of field investigations designed to quantify the effects of helmet-mounted display (HMD) technology on the performance of the dismounted infantry soldier. The objective of this field experiment was to measure soldier performance of land navigation and other mission tasks using current navigational equipment and to compare these data with performance using navigational information integrated on an HMD. Measures of stress, cognitive performance, workload, and situation awareness were also obtained.

In this study, each of 12 soldiers performed land navigation and other soldier tasks in each of two conditions. In one condition, the soldier was provided conventional land navigation equipment that included a paper map, protractor, lensatic compass, and a hand-held global positioning system (GPS) receiver. In the second condition, the soldier wore an HMD that integrated information supplied by a GPS and an electronic compass in each of two visual displays. The two displays included a map of the area to be navigated and a rolling compass display.

In both conditions, the soldier wore a backpack that contained the digitally aided soldier for human engineering research (DASHER) system. DASHER consists of a small commercial 386 computer, sound generation, a GPS, an electronic compass, and a stereo audio recorder. The system is a self-contained simulator-recorder that uses a position-based script to simulate connectivity with a command network presenting information about troop movement as well as data for land navigation. In the current equipment condition, DASHER was used for task administration and data collection only. In the HMD condition, DASHER generated the visual displays and associated navigational data presented on the HMD.

Each soldier was trained and tested in one equipment condition before being trained and tested in the other. Training included both classroom and field instruction in which the soldier was trained to a point at which he achieved an asymptote in the performance of land navigation and other soldier tasks using the equipment specific to that condition.

Measures of stress and cognitive performance were obtained on a day before training and testing, as well as before and immediately after training and testing in each equipment condition. Measures of stress were also obtained at the midpoint of each path that the soldiers navigated.

During testing in each condition, the soldier navigated a different unmarked path through densely wooded terrain. Each path was 3 kilometers long and consisted of four legs of different lengths. The soldier was instructed to navigate each leg of the path as quickly and as accurately as

possible, deviating from path center only as needed to avoid obstacles. The soldier's position was recorded at a rate of 1 Hz. Navigational accuracy, as determined by the root mean square error (*rmse*) deviation and the actual distance the soldier traveled, were measured in each leg of the path. Soldier velocity was also computed based on mission (task time included) and travel time. While navigating, the soldier was required to detect and identify objects that had been placed along the path. At pre-selected area coordinates within each path segment, the soldier received auditory messages initiating performance of other mission-related tasks. These tasks included Determine Magnetic Azimuth and Call for Fire. Similarly, the soldiers received information about troop movements and changes in waypoint location. In the current equipment condition, the soldier was required to plot changes in coordinates on the paper map. In the HMD condition, the soldier's displays updated automatically to depict these changes. At points along each path, the soldier received probe questions to assess his awareness of waypoint, landmark, and unit locations with respect to his position.

At the conclusion of testing in each equipment condition, the soldier rated his workload experience using the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). Behavioral Anchored Rating scales were administered to assess the impact of equipment on attention and the soldier's ability to perform concurrent tasks. These rating scales were also completed by an observer who accompanied the soldier throughout his mission. After testing in the HMD condition, each soldier completed a questionnaire that queried him about the frequency of use of the HMD and the two display formats. At the conclusion of testing in both conditions, a questionnaire was administered to obtain information about problems the soldier experienced and equipment preferences.

The results of the analysis of *rmse* deviation revealed a significant difference between Leg 4 and each of the preceding legs of the path ($p < .01$). This difference is attributed to terrain conditions in this latter leg and soldier fatigue. All other effects failed to reach significance at the .05 level of confidence. The analysis of distance traveled, however, indicated that soldiers navigated more efficiently, traveling significantly less distance using the HMD system than using current land navigation equipment ($p = < .05$). No significant differences were found between equipment conditions, however, in soldier velocity based on either overall mission (task time included) or travel time. In the current equipment condition, soldiers could view their GPS while moving and when terrain allowed, could sustain their movement for longer distances by spotting at far points using the lensatic compass. In the HMD condition, soldiers always stopped to consult their navigational displays.

In the analyses of soldier velocity, main effects were also found for path leg. These main effects are primarily attributed to significantly lower velocities achieved in Leg 3 where thorny vegetation was denser than in each of the other three legs of the path. The analyses revealed significant interactions among navigational equipment, leg, and a control variable (equipment, path, and order of presentation). These interactions are attributed to the significantly higher velocities achieved in Leg 1 of the path when soldiers navigated Path A using current equipment first. Velocities in subsequent legs of Path A using current equipment were significantly lower than in Leg 1, as were velocities in both equipment conditions in all legs of both test paths where equipment conditions and-or paths A and B were presented in a different order. This finding reflects the mildness of the terrain in Leg 1 of Path A, by comparison to the increased density of the vegetation in all other legs of both test paths. It may also indicate the soldiers' premature expectations that their task would be easy combined with their skill and confidence in navigating this milder terrain with the familiar lensatic compass.

Situation awareness, as measured by probe questions, was not significantly affected by test condition. No differences were found between conditions in the number of objects detected along the path or in time to perform other mission-related tasks (i.e., Determine Magnetic Azimuth and Call for Fire). However, in the current equipment condition, manual map updates noting changes in unit position and waypoint destination were more time consuming by comparison to the HMD condition where such changes were displayed automatically. The soldiers' overall ratings of workload, as measured by the NASA-TLX, were significantly higher using current equipment than using the HMD system ($p < .05$). Ratings of mental workload were also higher in the current equipment condition ($p < .05$). This latter finding may reflect the differences in the level of automation between current equipment and the HMD system, which impacted the amount of mental processing required to perform some mission tasks. Also, in the HMD condition, soldiers noted that the displays provided them all the information they needed and were "easy to use, read and follow".

The results of the analyses of the psychological stress perception measures indicated little to no psychological stress associated with either experimental condition. Therefore, although differences were found in the current equipment condition between earlier measures of salivary amylase (i.e., baseline and during test) and post-test levels ($p < .05$), these differences are not attributed to an increase in psychological stress but rather to an increase in physiological stress related to an increase in physical activity imposed by manipulation of more equipment. No differences were found between conditions in cognitive performance. In the HMD condition, however, post-performance scores on spatial rotation were unexpectedly higher than pre-measure scores ($p < .05$). This finding is attributed to practice that the soldiers received in mentally rotating the HMD's map display that was fixed in the north-up direction. Generally, differences were also found between baseline and post measures for word recall and addition. As expected, performance was significantly higher for the baseline measure of word recall ($p < .05$). However, baseline scores were significantly lower than the post measure for the addition task ($p < .05$). As for spatial rotation, this latter finding is attributed to practice effects. In both the HMD and current equipment conditions, soldier tasks involved mental math.

The findings of this investigation appear to indicate that the effective integration of navigational information on an HMD can measurably enhance navigational efficiency by providing the soldier readily accessible and easily interpretable information about his or her position. Although the reduction in the distance traveled by the HMD-equipped soldier did not bring about the expected increase in velocity, greater efficiency in navigating from point to point can potentially result in lower levels of fatigue and improved performance upon arrival at the soldier's destination. Significant reductions in the soldier's mental workload, as well as a decrease in the soldier's overall workload experience, are also achievable using an HMD. However, it is important to note that, although the findings of this study appear to favor the HMD, results may differ with other display formats and increases in the quantity of information displayed. Whether the above advantages in performance and reduced workload using the HMD are attributable to the effective integration of displayed information, head-mounting of the displays, or both, remains uncertain.

A COMPARISON OF SOLDIER PERFORMANCE USING CURRENT LAND NAVIGATION EQUIPMENT WITH NAVIGATION INFORMATION INTEGRATED ON A HELMET-MOUNTED DISPLAY

INTRODUCTION

A helmet-mounted display (HMD) is a part of the integrated headgear assembly sub-system (IHAS) which is a component of the Land Warrior System. The Land Warrior System is expected to enhance the soldier's performance and survivability in the future battlefield. However, the effects of HMDs on soldier performance, whether positive or negative, have not been quantified.

Although HMDs have been used successfully in military aviation, they have not been used without concern as to their effects on pilot perception and attention (Fischer, Haines, & Price, 1980; Iavecchia, Iavecchia, & Roscoe, 1988; Weintraub & Ensing, 1992), and the role they might have played in aviation accidents (Rash, Verona, Crowley, 1990). An abundance of literature relates to the design of HMDs for the aviator (Hughes, Chason, & Schwank, 1973; Foyle, McCann, Sanford, & Schwirtzke, 1993; Larish & Wickens, 1991; Wickens & Long, 1995), but there is little that focuses on the design of these displays for the dismounted soldier or the effects HMDs might have on the soldier's performance.

HMDs are not a uniform class of displays. They include discriminating differences such as color versus monochrome, monocular versus binocular, opaque versus "see through," visually coupled and uncoupled, and display formats with differing frames of reference. Yeh and Wickens (1997) examined research issues associated with the use of HMDs, addressing issues that characterize different display formats and performance measurement using these displays. They report literature that contains few field studies, and findings that are somewhat mixed on the performance advantages of HMDs.

In 1995 and 1997 reports about tactical displays for soldiers, the National Research Council (NRC) provides a broad review of the available literature concerning HMDs, noting data gaps and research issues that must be addressed to determine the usability of these displays by the dismounted soldier. Among NRC's concerns are that HMDs might compete for the soldiers' attention, reduce their awareness of the situation immediately around them, and conflict with their performance of other critical tasks.

Previous modeling and system analysis efforts have attempted to estimate the effects of the Land Warrior System on mission performance and workload (Adkins, Murphy, Hemenway, Archer, & Bayless, 1996; McNinch, 1995). "Best guesses" were often used to derive these estimates because data and information about the use of this equipment by the soldier were lacking.

In support of the soldier and the goals of the Land Warrior System, the Human Research & Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) is conducting research to quantify the effects of HMDs and alternate display technologies on soldier performance, and trade-offs between visually and auditorially displayed information. This research involves an iterative process among modeling, field, and laboratory experimentation (see Figure 1). The process includes the development of an analytical model, which focuses on the high-driver tasks of the military occupational specialty (MOS) 11B infantry soldier. The model is the foundation in the development of scripted tactical scenarios that are enacted by infantry soldiers in a series of field experiments. During these field experiments, soldier performance using HMDs and alternate display technologies is measured and compared with that of the soldier using current equipment. The data and information collected during these experiments are used to refine and validate the model and to define the focus of ensuing field studies. The results of these studies also feed into the design of laboratory investigations that quantitatively explore visual and auditory issues in attention, perception, detection, and recognition as they relate to the design and use of HMDs by the dismounted soldier.

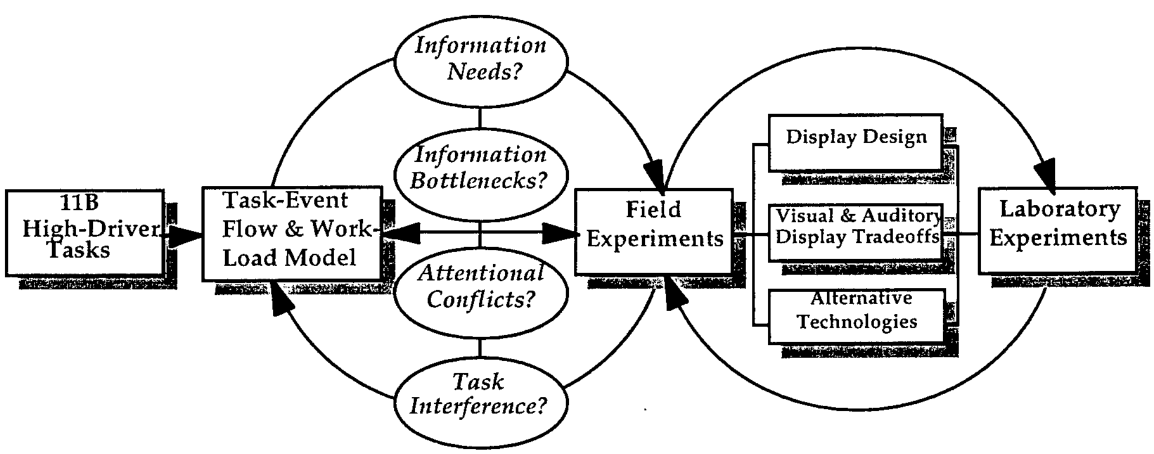

Figure 1. Iterative approach to examining the effects of HMDs and alternate display technologies and techniques on infantry soldier performance.

As a first step in this research process, ARL queried subject matter experts (SME) to identify tasks of the 11B soldier that might benefit most from HMD technology. These SMEs were from the Infantry Center at Ft. Benning, Georgia, and all were familiar with HMDs and the Land Warrior System. Many of the tasks that the SMEs identified were land navigation tasks. These tasks, along with other critical tasks of the 11B soldier, were used to construct a Task-Event Flow and Workload model within the context of a movement-to-contact/attack mission scenario. In this model, the soldier uses more conventional land navigation equipment: the lensatic compass and paper map. However, in recent battlefields, some soldiers have also been provided a global positioning system (GPS) receiver. This lightweight, hand-held device provides the soldier his or her position coordinates at a rate of 1 Hz; however, a lensatic compass is still required to provide information about the soldier's azimuth orientation. What would be the effect on soldier performance if the information provided by the paper map, compass, and GPS unit were all integrated on an HMD?

The present study was the first in a series of field experiments that are a part of the process described. The study was a joint effort by ARL and partners within the Federated Lab Consortium: Sytronics, Inc., and Rockwell International. Rockwell International supplied the HMD and the computer that drives it (the Trekker™ System). Sytronics integrated this equipment with an electronic compass and provided the programming support for display of navigation and other tactical information to the HMD-equipped soldier. Rockwell and Sytronics also developed a unique plan to use this equipment with a GPS to automatically and unobtrusively initiate tasks and measure and record the soldier's performance in both test conditions (Marshak, Glumm, Marzen, Wesler, & Scheid, 1996).

OBJECTIVE

The objective of this field experiment was to measure soldier performance of land navigation and other mission tasks using current navigational equipment and to compare these data with performance using navigational information integrated on an HMD. Measures of stress, cognitive performance, and workload were also obtained.

METHOD

Test Participants

Twelve male infantry soldiers participated in this study. The soldiers ranged in age from 19 to 38 years with an average age of 29. Their MOSs were Dismounted Infantry (11B) and

Mechanized Infantry (11M). Their time in service and time in MOS both ranged from 1 to 20 years with an average of 9 years. When asked to rate their land navigation skills, seven of the soldiers rated their skills as "good" or "excellent," three "neither good nor bad," and three "poor" or "fair." All met visual acuity requirements established for this study of 20/20 in one eye and at least 20/30 in the other eye (corrected or uncorrected) and passed tests for color and stereo vision.

Apparatus

The navigational equipment used by the soldiers in each of the two experimental conditions is listed in Table 1. In the current equipment condition, the soldier used more standard land navigational equipment that included a paper map, protractor, lensatic compass, and a hand-held GPS (see Figure 2). In the HMD condition, the soldier wore an HMD (see Figure 3) that integrated information supplied by a GPS and an electronic compass in each of two visual displays. The two displays included a map of the area to be navigated and a rolling compass display. In both conditions, the soldier wore the standard battle dress uniform (BDU) and the personal armor system for ground troops (PASGT) helmet. The soldier carried a dummy M16 and an Army lightweight carrying equipment (ALICE) backpack.

Table 1

Navigational Equipment by Condition

Equipment	Condition	
	Current	HMD
Paper map	x	
Protractor	x	
Lensatic compass	x	
Global positioning system	x*	x
Keypad and mouse	**	x
Electronic compass	**	x
Computer	**	x
HMD		x
Displays		
Map		x
Rolling compass		x

*One GPS used in hand-held mode for land navigation; second GPS in backpack used for task initiation and data collection.
**Used for task initiation and data collection only.

Figure 2. Conventional land navigation equipment.

Figure 3. HMD-equipped soldier.

In both conditions, the soldier's backpack contained a small 386 computer, GPS, electronic compass, and an audio cassette recorder. This equipment was integrated by Sytronics, Inc., in a system called the digitally aided soldier for human engineering research (DASHER). DASHER, which included a 3.6-kilogram (8-lb) 12-volt battery, weighed approximately 12.7 kilograms (28 lb). During the study, DASHER was used in both conditions to initiate mission tasks and record soldier performance. The system used a position-based script to simulate connectivity with a command network that presented information auditorially about troop movement and changes in waypoint location. The stereo cassette recorder was used to monitor computer output and record soldier comments. DASHER's software was written in Borland C++. In the current equipment condition, DASHER was used for task administration and data collection only. In the HMD condition, DASHER generated the visual displays and associated navigational data presented on the HMD. In both conditions, computer interface and response to various scenario events were input to a keypad and glide-point mouse worn on the soldier's belt. A description of the navigational equipment used by the soldiers in the current equipment and HMD conditions of the study, along with the components of the DASHER system, follows.

Lensatic Compass

In the current equipment condition, the soldier used a standard military lensatic compass to determine his orientation and the azimuth which he was traveling. The compass has a vertical sight in the lid and a separate lens that the soldier uses to align a landmark and read the bearing.

Paper Map and Protractor

In the current equipment condition, the soldier was provided a paper map of the area of operation. In the HMD condition, this same map was one of two digital displays used for navigation. The map was derived using digital ortho-photography and was accurate to within 0.46 meter (1.5 feet). It depicted streams, marsh, trees and foliage, dirt paths and improved roads, and other landmarks provided on standard military maps. A legend defining these terrain features and landmarks was included. Because the area of operation in this field experiment would appear the size of a postage stamp on a standard 1:50000-meter military map and would not allow the needed level of detail, the scale of the map was increased to 1:6000 meter. A protractor was also constructed based on the standard military protractor (Graphic Training Aid 5-2-12) for use with this map in plotting position coordinates and in calculating distance and azimuth.

Global Positioning System Receiver

The GPS used in this investigation is called the PLGR. It is a hand-held unit (AN/PSN-11) developed for the military by Rockwell International and when de-encrypted (P[Y] mode), can provide an accuracy of ±10 meters or better. In both test conditions, the GPS provided position coordinates that initiated specific task events. In the HMD condition, position information supplied by the GPS, along with orientation information supplied by an electronic compass, was integrated into the two navigational displays. In the current equipment condition, the soldier was provided position coordinates on a hand-held GPS. The hand-held GPS was used primarily in the navigational mode to provide information similar to that provided in the HMD condition. This information included the soldier's distance in meters to the left or right of path centerline and the range to his next waypoint. Position information supplied by the GPS was updated at a rate of 1 Hz.

Electronic Compass

An electronic compass (C100), developed by KVH (not an acronym) Industries, was used to supply orientation information. This compass is based on magnetic flux sensing technology and has ±0.5° (±10 mils) accuracy with 0.1° (1 mil) resolution. The compass was located in the soldier's backpack and was used to measure the soldier's azimuth orientation at a rate of 1 Hz.

Helmet-Mounted Display and Computer (the Trekker™ system)

The Land Warrior's IHAS was unavailable at the time of this field experiment. A suitable surrogate HMD, called the Trekker™, was supplied by Federated Lab partners at Rockwell International who developed the system. The Trekker™ 2010 consists of a headset and a 386 computer (see Figure 4). The headset consists of an occluding, monocular display developed by Koppin, and a boom microphone. The display is a monochrome cathode ray tube (CRT) with 640H x 480V lines. Focus and brightness controls are integrated into the headset. The display slides left or right along the top of the unit to accommodate the desired viewing eye. The monocle assembly rotates on its arm and can be manipulated vertically to provide adjustment for eye relief (fore-aft) and display stowage. For this investigation, the HMD was secured to the soldier's PASGT helmet by a webbed strap, and the display was positioned over the eye that was not used to aim the M16 rifle (non-dominant eye). A magnetic switch sensor was mounted on the HMD headband and was used to measure the frequency and duration of HMD stowage. The weight of the HMD is approximately 0.45 kilogram (1.0 pound). The 386 processor that drives the HMD runs at 50 megahertz with 16 megabytes (MB) internal dynamic memory and a 540-MB hard drive. The Trekker™'s two PC card slots contain serial interfaces to communicate with the GPS and the electronic compass.

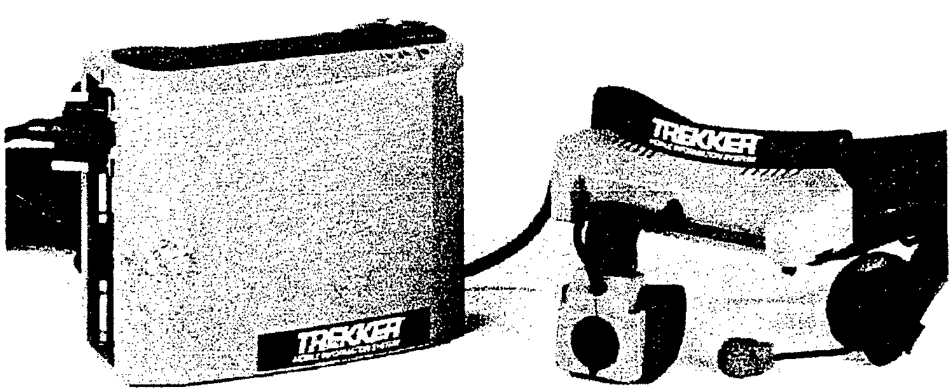

Figure 4. The Trekker™ 2010 system: 386 processor and head-mounted display.

In this study, the HMD integrated navigational information in each of two display formats. The two displays included a map of the area to be navigated and a rolling compass display. The map display, shown in Figure 5, integrated the map of the area of operations, with position and orientation information. Symbology was overlaid on the map to indicate the position of friendly and enemy units. The soldier's location and orientation was indicated by a circle with a pointer. The planned path was indicated by a series of diamond-shaped, waypoint icons connected by a solid line. The waypoint to which the soldier was traveling was darkened. Heading and distance information to that waypoint was provided at the right of the display, along with the estimated position error (EPE) of the GPS indicating the system's current margin of error. System interrupt messages were also provided to indicate equipment malfunctions and the status of data collection. Each of these visual interrupt messages was accompanied by an auditory alert (e.g., "GPS down!" or "compass down!").

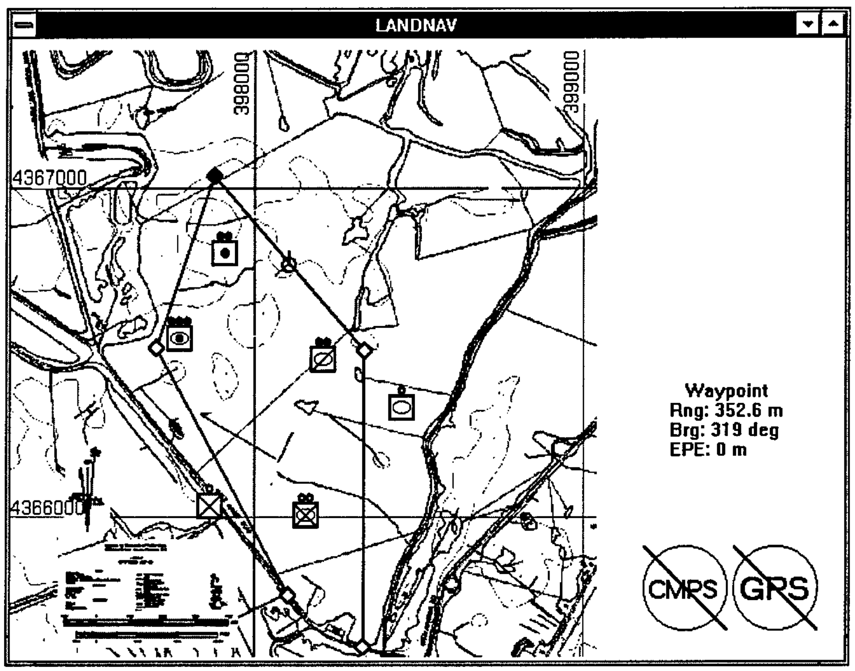

Figure 5. The HMD's digital map display with overlaid symbology and navigational information.

The rolling compass display was a linear tape design that covered 180° of the soldier's forward field of view (FOV) within the 40° FOV of the display (see Figure 6). This display provided information similar to that on the map display with the exception of terrain features and landmarks. Like the map, the rolling compass automatically updated to show changes in soldier and other unit positions. An arrow beneath the rolling scale pointed to the soldier's current heading with respect to his next waypoint. The waypoint to which the soldier was traveling was indicated by a diamond-shaped icon that appeared above the compass tape at the azimuth the soldier must travel to attain it. The distance between the soldier and this waypoint appeared below the icon. Symbology depicting the position of enemy units was shown above the waypoint along with the soldier's distance from these units. Enemy units and waypoints that were more than 180° left or right of the soldier's direction of travel appeared at the sides of the scale when they were within 500 m of the soldier's position. Friendly unit positions were shown below this information. The soldier's coordinates were shown at the bottom of the display along with the EPE of the GPS. As in the map display, system interrupt messages and associated auditory alerts were also provided. The soldier could choose to view either the rolling compass or the map display by depressing a button on a keypad labeled "toggle." The frequency and duration of use of each display were recorded.

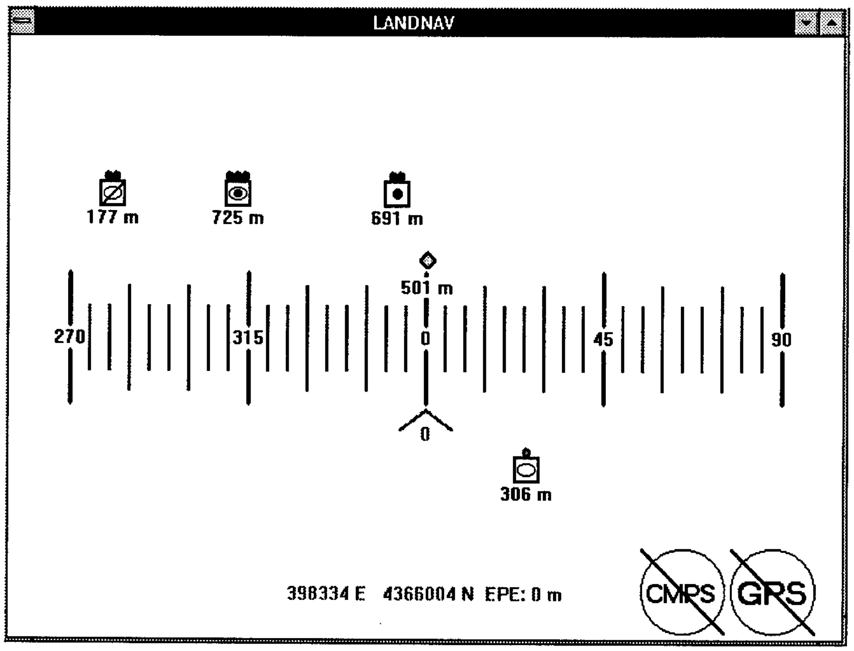

Figure 6. The HMD's rolling compass display including symbology and navigational information.

Keypad and Glide-Point Mouse

Display control and computer interface, along with soldier responses to scenario events and mission tasks, were input with a keypad and glide-point mouse developed by Alps (see Figure 7). A wooden case was constructed to protect the keypad and preclude inadvertent input. The case incorporated loops that allowed the keypad to be strung on the soldier's belt. Quick access to the keypad and mouse was achieved through a panel held in place by Velcro®. The keys that the soldier used in response to specific tasks were labeled for easy recall of functions.

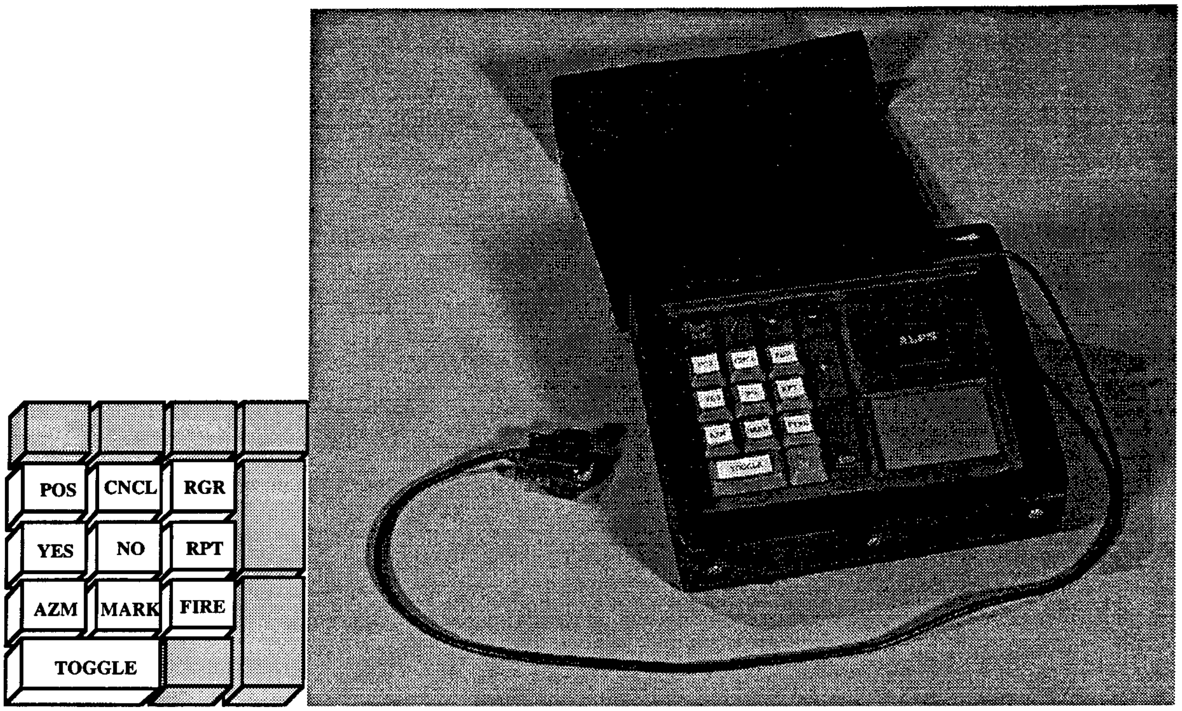

Figure 7. Keypad and glide-point mouse.

Procedures

Test Participant Screening and Baseline Measures

A visual acuity test at far and near distances was administered to the military volunteers to ensure 20/20 vision in one eye and at least 20/30 in the other eye, corrected or uncorrected. Volunteers were also required to pass tests of color and stereo vision. Test participants completed a questionnaire to obtain pertinent demographic and background information, including information about previous training and experience in the use of the equipment to be used in the study (see Appendix A).

Stress tests and a cognitive performance test battery were administered to familiarize the soldier with the procedures to be followed in the collection of these data during training and testing and to obtain baseline measures. The stress tests included the Salivary Amylase Field Test and a battery of stress questionnaires (see Appendix B). Cognitive performance was measured using the Cognitive Performance Assessment for Stress and Endurance or CPASE (see Appendix C).

During this period, the soldier also received instruction in the assessment of his workload experience in accordance with the prescribed procedures of the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). The NASA-TLX uses rating scales to assess mental, physical, and temporal demands, performance, effort, and frustration. In this technique, a weight is initially obtained for each of the six workload factors based on the subject's responses to pair-wise comparisons among these factors. In these comparisons, the six factors are presented in 15 possible pairs, and for each pair, the subject is asked to circle the factor that he or she perceives to contribute more to his or her workload experience. The subject then completes rating scales that provide a measure of the magnitude of the workload for each factor. Those factors perceived by the subject to be most important in his or her workload experience are given more weight in computing the overall workload score. Definitions of each of the six workload factors assessed, the pair-wise comparisons, and rating scales are provided in Appendix D.

Training

The duration of training and testing for each of the 12 soldiers was 4 days. Training and testing in one of the two equipment conditions were conducted on Day 1 and Day 2, respectively. Training and testing in the second condition were conducted on Day 3 and Day 4. Two soldiers were trained and tested at one time. On Day 1 and 2, one soldier was trained in one equipment condition while the second soldier was trained in the other. On Day 3 and 4, the conditions in which these soldiers were trained and tested were reversed.

In each condition, training included both classroom and field instruction during which the soldier was trained to a point at which he achieved an asymptote in the performance of land navigation and other soldier tasks using the equipment specific to that condition. The Salivary Amylase Field Test, stress questionnaires, and the CPASE test battery were administered immediately before and after training in each condition.

Current Equipment Training

Training with current equipment began with a pace count followed by instruction and practice in the operation of the lensatic compass and the GPS receiver. GPS training focused on those modes that the soldier needed to retrieve information similar to that supplied in the HMD condition (e.g., "position" and "navigation" modes). The soldier also received instruction and practice in the use of the protractor and paper map. In this portion of the training, the soldier was provided the coordinates of paths similar to those that he would navigate during testing. In each practice run, the soldier was required to plot a different path segment and compute its distance and azimuth. The soldier performed consecutive runs until he reached an asymptote in time and error.

Initial instruction in the performance of other mission tasks was provided in simulated "walk throughs" of the training path. For this portion of the training, the soldier was seated with his back to a computer monitor that displayed the training path. The instructor, aided by icons denoting scenario events, "walked" the cursor along the path, initiating auditory messages relayed through speakers that would cue the soldier to perform a specific task. In the initial "walk through," the instructor described the procedures that were to be followed in the performance of each task and the required inputs to the keypad and mouse. In ensuing walk throughs, the soldier described these procedures to the instructor and practiced these inputs with the keypad and mouse.

Before field instruction, the soldier was required to plot the coordinates of the training path and compute the azimuth and distance he was to travel between waypoints. The soldier was also required to plot the "current" position of enemy and friendly units. Time and errors were recorded. The soldier was informed of any errors and corrected the map accordingly. The soldier then completed three runs on the actual training path. The training path consisted of three 200-meter segments for a total path length of 600 meters. In each of the three segments, the soldier performed all tasks that would be performed during testing. The soldier was accompanied on the training path by a "lane walker." This lane walker also accompanied the soldier throughout testing in each equipment condition. The primary purpose of the lane walker was to ensure the soldier's safety. Other functions included equipment troubleshooting, data collection, and administration of the stress tests and cognitive test battery.

HMD Training

In the HMD condition, the soldiers were instructed in the interpretation of the symbology and the reading of navigational information provided on the digital map and rolling compass displays. As during training in the current equipment condition, instruction and practice in the performance of mission tasks were provided in simulated "walk throughs" of the training path. However, during training in the HMD condition, the soldier viewed the training path on the computer monitor, as he would when wearing the HMD. The soldier then completed three runs on the 600-meter training path, performing all tasks that would be performed during the test period.

Testing

During testing, each of the 12 soldiers navigated a different path in each of the two equipment conditions. As shown in Table 2, the order of presentation of these conditions and paths was counterbalanced among the 12 soldiers.

Table 2

Design Matrix and Counterbalancing Scheme

Subject	Condition (1 and 2) X path (A and B)	
1	2A	1B
2	1B	2A
3	2B	1A
4	1A	2B
5	2A	1B
6	1B	2A
7	2B	1A
8	1A	2B
9	2B	1A
10	1A	2B
11	2A	1B
12	1B	2A

The two test paths that the soldiers navigated during the investigation are shown in Figure 8. The total length of each path was 3 km. Each path consisted of four segments or legs. The lengths of these legs were 500 m, 700 m, 850 m, and 900 m; however, the order of presentation of leg length was varied between paths. Each path consisted of five waypoints (WP): WP0 (start point), WP1, WP2 (midpoint), WP3, and WP4 (end point). The terrain is characterized as generally flat with contours of 2 to 3 feet. Much of the area is densely wooded and includes small streams and marshy areas with standing water. The ground is covered with fallen trees and branches, concealed by grass approximately 8 inches tall. Each path contains some thickets and briar patches of varying densities. Except for some short, muddy sections of path that lack ground cover, the hardy grasses and vegetation within this area recover quickly from footsteps, revealing no evidence of previous travelers.

Before testing in each equipment condition, the soldier was administered the Salivary Amylase Field Test, stress questionnaires, and the CPASE test battery. The soldier was then accompanied by the lane walker toward the point of departure. Within ±20 meters of the starting point of the test path, the soldier received an auditory message stating that he had reached the initial waypoint and to notify the lane walker. A final check of the equipment was performed, including a check of all GPS receivers to ensure an EPE of ±20 meters or better. The lane walker reminded the soldier of the mission and the tasks that he was to perform. The soldier was also reminded that all tasks were equally important, as were the speed and accuracy with which he performed these tasks.

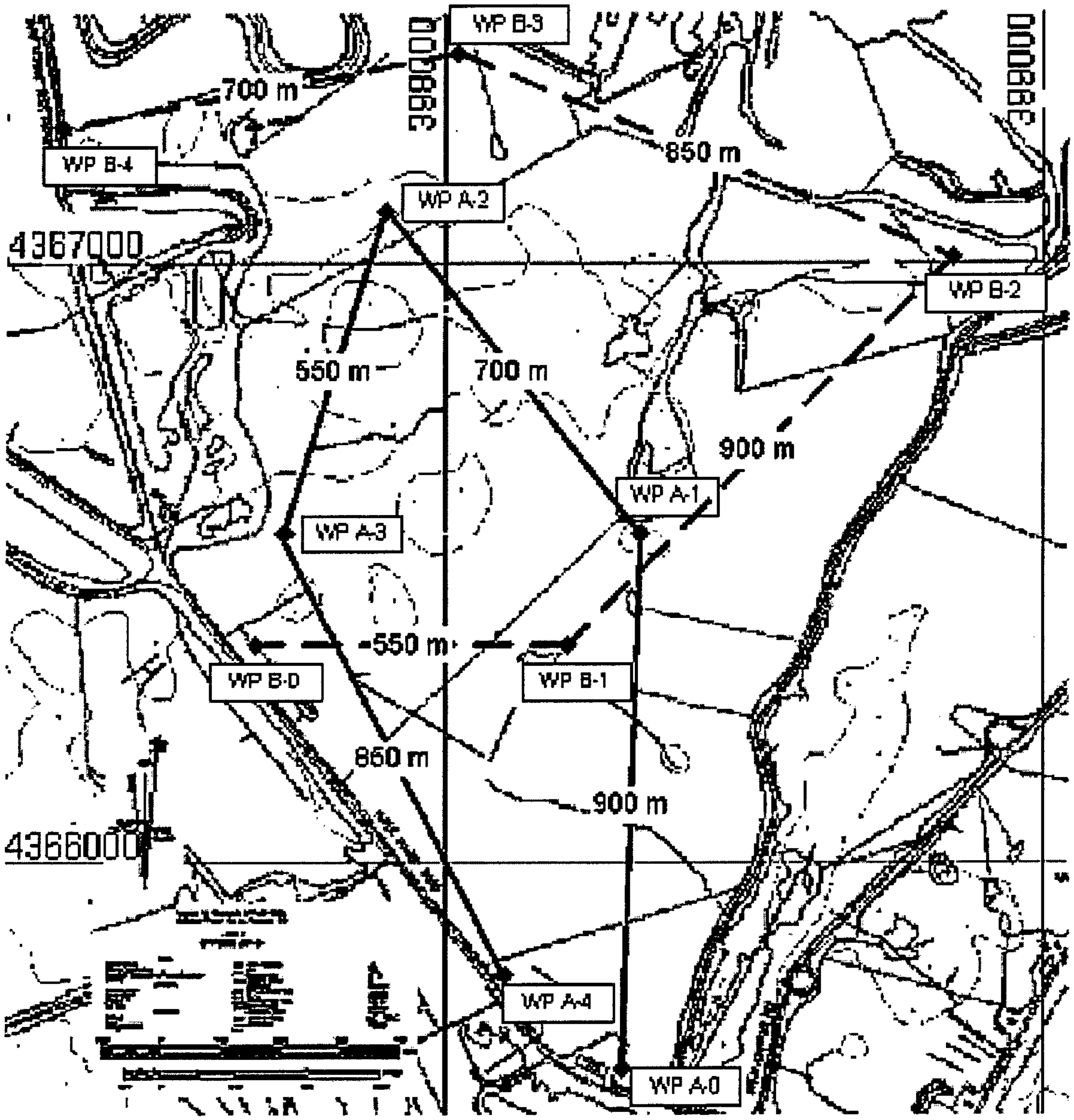

Figure 8. Test paths A and B with waypoint positions and leg lengths.

As the soldier navigated along the path, he was required to detect and identify objects. The soldier also received auditory messages that directed him to perform other mission tasks. A description of the tasks the soldier performed during the mission, along with the instructions the soldier was given in performing these tasks, follows:

Navigation

The soldier was instructed that speed and accuracy were equally important when traveling from waypoint to waypoint. He was told to maintain his position on a straight-line course, deviating only as far as necessary to avoid obstacles. In case of a detour, he was to return to the path as soon as possible and resume his straight-line course to the next waypoint. The lane walker, equipped with a separate GPS, provided one warning at 20 meters' deviation from the path and one warning at 40 meters' deviation, with a reminder that the soldier should check his navigational equipment. At 60 meters' deviation from the path, the lane walker guided the soldier back to path center. The soldier's absolute position was recorded at a rate of 1 Hz, along with the EPE of the GPS. Navigational accuracy was examined from two perspectives: the root mean square error (*rmse*) deviation from the straight-line path and the actual distance the soldier traveled. The *rmse* deviation between a specified path and the path traveled has been used as a measure of performance in previous studies (Kelly, 1969; Purvis, 1991). As an average, *rmse* allows direct comparison of paths of dissimilar length. However, Purvis (1991) found that strategies used by pilots when landing in cross-wind conditions unduly inflated the *rmse*. In the present study, there was concern that the *rmse* might be similarly inflated by strategies used by infantry soldiers in avoiding terrain hazards and other obstacles during land navigation. Therefore, the actual distance traveled by the soldier was used as a second measure of navigational accuracy. Measures of the soldier's velocity within each leg of the path were computed by dividing the time to navigate each leg by the actual distance the soldier traveled. Velocity was computed for both mission time and travel time. Mission time was computed from the time of departure from one waypoint to the time of arrival at the next waypoint and included the time to perform all mission-related tasks. Travel time was based on mission time minus task time. The time spent at each WP was not included in calculations of mission or travel time, nor was any time spent in diagnosing and resolving equipment problems.

Detect and Identify Objects

Five objects were positioned within each leg of each path. Each leg included one mine, one antenna, one oil drum, and two enemy personnel (wooden silhouettes). The order in which these objects appeared within each leg and the distance between objects were randomized. Immediately upon detection of an object, the soldier was required to depress the "report" button on the keypad, annotating the data file. The soldier then identified the object describing the size, activity, location, unit, time, and equipment (SALUTE). The SALUTE report was recorded by an audio recorder located in the soldier's backpack.

Determine Magnetic Azimuth

At a predetermined area coordinate within each leg of the test path, the soldier received an auditory message stating "Mark position of the next waypoint and determine magnetic azimuth." In the current equipment condition, the soldier oriented his body in the direction of his next waypoint and depressed a button labeled "mark" on the keypad. He then read his azimuth from the lensatic compass and depressed the "azimuth" button. In the HMD condition, when the soldier oriented his body in the direction of his next waypoint and depressed the "mark" button, a line was interjected within the map display extending from the icon denoting his position toward the next waypoint. If the line did not intersect the center of the waypoint, the soldier depressed the "cancel" button which withdrew the line. The soldier then reoriented his body and once again depressed the "mark" button. If the line now intersected the waypoint, the soldier read the azimuth presented on the map display and depressed the "azimuth" button. For both conditions, time to perform this task was based on the time from initiation of the auditory message to the time the soldier depressed the "azimuth" button.

Call for Fire

At a predetermined area coordinate within each segment of the test path, the soldier received an auditory message stating "Align on last reported target and call for fire." This target or object was normally located within ±20 m of the soldier's position. In the current equipment condition, the soldier oriented his body in the direction of the object and depressed the "mark" button. He then depressed the "position" button on the GPS to obtain the coordinates of his position. He derived an estimate of the coordinates of the object by estimating its distance from his position and using the lensatic compass to determine its azimuth. The soldier then spoke the coordinates of the object aloud and depressed the "fire" button. In the HMD condition, the soldier oriented his body toward the object and depressed the "mark" button. A line was interjected within the map display that extended from the soldier's position toward the object the soldier was facing. The line was marked in increments of 25 meters. Using the glide-point mouse, the soldier positioned the cursor at the point on the line at which he estimated the object to be and depressed the left mouse button. The coordinates of the object then appeared in the display. If for any reason the soldier was not satisfied with this input or the resultant object coordinates, he could withdraw the line by depressing the "cancel" button and could begin again. If the soldier was satisfied with the input and the object's coordinates, he spoke the coordinates of the object that appeared on the map display and depressed the "fire" button. For both conditions, time to perform this task was based upon the time from initiation of the auditory message to the time the soldier depressed the "fire" button.

Fragmentary Order (FRAGO)

At a predetermined waypoint within each path, the soldier received an auditory message changing the coordinates of the next waypoint to which he was to navigate. For example, the message stated "Prepare for map update--Move waypoint 3 from 4366125 northing 398345 easting to 4367236 northing 398006 easting." In both conditions, the message repeated every 45 seconds until the soldier acknowledged that he noted the change by depressing "Roger." In the current equipment condition, the soldier wrote the new coordinates on the map. He then plotted these new coordinates and calculated the distance and azimuth he must travel to the new waypoint. Upon completion of this task, the soldier depressed the "report" button. The lane walker informed the soldier of any errors in plotting or calculation, and the soldier corrected the map accordingly. Time to perform this task was calculated from the time between depression of the "Roger" button to the time of depression of the "report" button. In the HMD condition, the map and rolling compass displays updated automatically to reflect the new waypoint, and the soldier only needed to depress the "Roger" button.

Troop Movements

At pre-planned area coordinates along each path, the soldier received auditory messages changing the coordinate position of enemy or other friendly units within the area. For example, the message stated "Prepare for map update--Move enemy unit reported at 4366125 northing 398245 easting. Unit is now located at 4367236 northing 398006 easting." As for the FRAGO, the message repeated every 45 seconds until the soldier depressed the "Roger" button to acknowledge the change. In the current equipment condition, the soldier plotted this change in position on the paper map; in the HMD condition, the soldier's displays updated automatically to reflect these troop movements. As for the FRAGO, the time to perform this task was calculated from the time between depression of the "Roger" button to the time of depression of the "report" button. In the HMD condition, the map and rolling compass displays updated automatically to reflect the unit's new position, and the soldier only needed to depress the "Roger" button.

Probe Questions

One presumed advantage of HMDs is the increased availability of information to the wearer. To test this hypothesis, a measure of awareness was obtained using probe questions. This method of measuring awareness was first used by Marshak, Kuperman, Ramsey, and Wilson (1987) and was refined by Amburn (1994). Awareness relates to the information that an individual can recall from his or her short-term memory. Typically, specifics are not easily recalled. Therefore, in the probe question method, the question protocol is limited to a recognition response of a simple "yes" or "no". The "yes-no" format also allows analysis of responses using signal detection theory. A simple fact in short-term memory is treated like a signal embedded in the noise of other memories. The sensitivity measure (d′) measures the salience of information in short-term memory. In the present study, 16 probe questions (four questions per path leg) were delivered to the soldier by computer-generated audio at pre-determined area coordinates within each path. These questions were used to assess the soldier's awareness of information provided on the paper map and digital displays in both the current equipment and HMD test conditions, respectively. The questions queried the soldier about his heading or the location of waypoints, landmarks, or other units with respect to his position (example: "Is there an enemy unit within 100 meters to your right?"). The soldier responded to these questions by depressing the "yes" or "no" buttons on the keypad. In the current equipment condition, the soldier was not allowed to consult the map until he responded to the question. Similarly, in the HMD condition, the soldier's displays temporarily blanked.

Other During and Post Measures

At the midpoint of the path, the soldier was administered the Salivary Amylase Field Test and stress questionnaires. These stress tests were also administered immediately upon path completion, along with the CPASE test battery. Upon returning to the command center, the soldier assessed his workload experience using the NASA-TLX. Both the soldier and lane walker completed questionnaires (Behavioral Anchored Rating scales) that assessed the impact of equipment on attention and the soldier's ability to perform concurrent tasks (see Appendix E). After testing in the HMD condition, each soldier completed a questionnaire that queried him about the frequency of use of the HMD and individual display formats. After completion of testing in both conditions, a post-test questionnaire was administered to obtain information about problems the soldier experienced and his equipment preferences. Post-test questionnaires are provided in Appendix F.

RESULTS

Land Navigation

Post Processing of Position Data

Raw position data were logged from the PLGR using the P(Y) precision military signal. The precision signal can achieve ±10-meter accuracy or better without needing a differential

GPS base station. However, as shown in Figure 9, these raw data contained considerable random noise. Processing of the raw data was necessary to improve resolution.

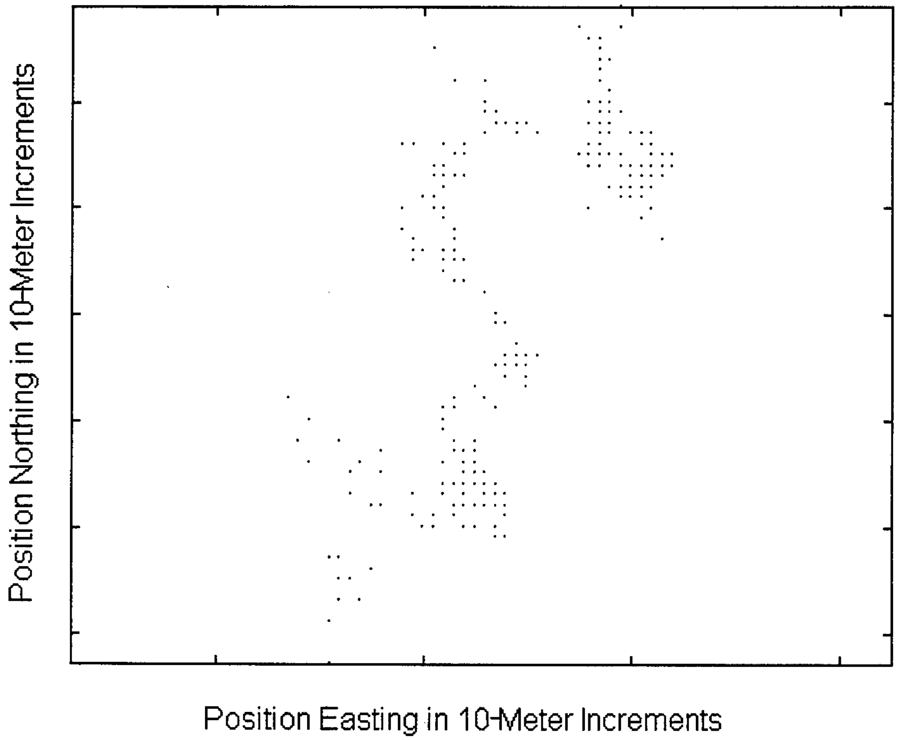

Figure 9. Raw data (300 points) from the GPS receiver using the P(Y) precision code (scale increments = 10 meters).

A simple moving average was employed to filter the random noise. Each data point was replaced with the average of the current point with five earlier and five later samples. The size of this "window" was empirically determined, based on examining different window sizes on pilot data. The effects of this filtering are shown in Figure 10. As can be seen, the soldier's path and other details, such as changes in velocity, excursions around obstacles, and GPS drift, are more evident. Very large excursions caused by momentary loss of GPS satellite data, as well as excursions greater than 70 m from the path, were excluded from the data analysis. These latter excursions were rare, given that the soldier was directed back to the path at deviations of 60 m.

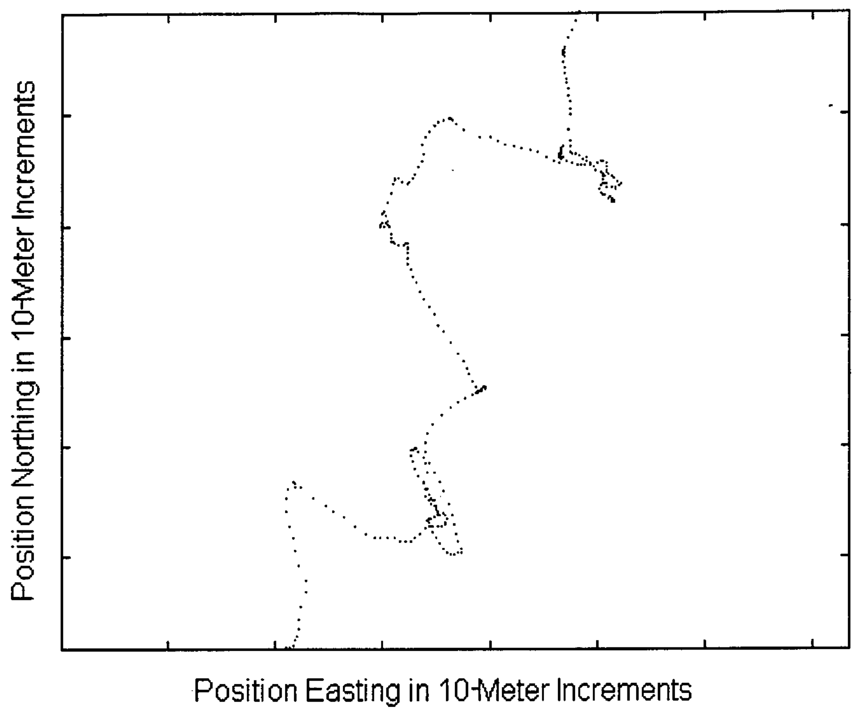

Figure 10. GPS data filtered using a ±5-point moving window average (scale increments = 10 meters).

Navigational Error

For this study, navigational accuracy was examined from two perspectives: *rmse* deviation from the straight-line path and the actual distance traveled by the soldier. For each measure, the data were subjected to a repeated measures analysis of variance (ANOVA) with equipment (current equipment and HMD) and path leg (Leg 1 through 4) as within-subject effects, and a control variable (CCON) as a between-subjects effect. The control variable consisted of the four combinations of path (A and B) and equipment (current and HMD), and the order of presentation, which were counterbalanced.

ANOVA Results of Root Mean Square Error (*rmse*)

The results of the ANOVA performed on the *rmse* data are presented in Table 3. Although the trend in *rmse* appeared to favor the HMD condition, differences in *rmse* between the HMD and current equipment conditions failed to reach statistical significance at the .05 level of confidence. A significant main effect, however, was found for path leg (see Figure 11), $F(3,9) = 4.97$, $p = .008$, with RMSEs of 13.93 m (Leg 1), 14.80 m (Leg 2), 13.68 m (Leg 3), and 17.27 m (Leg 4). Post hoc analyses indicate that the *rmse* in Leg 4 was significantly higher than in Legs 1, 2, or 3. This difference may be attributable to fatigue. However, it may also suggest that soldiers were more intent on completing the path than on the accuracy with which they maintained path center. All other effects failed to reach significance at the .05 level of confidence.

Table 3

ANOVA Results of *rmse*

Source	DF	ANOVA SS	Mean square	F value	Pr > F
CCON	3	158.758	52.919	0.44	0.732
SUBJ(CCON)	8	967.000	120.000		
EQUIP	1	218.631	218.631	3.39	0.103
CCON*EQUIP	3	272.454	90.818	1.41	0.310
SUBJ*EQUIP(CCON)	8	515.723	64.465		
LEG	3	490.577	163.526	4.97	0.008
CCON*LEG	9	406.442	45.160	1.37	0.255
SUBJ*LEG(CCON)	24	789.852	32.911		
EQUIP*LEG	3	153.266	51.089	1.22	0.325
CCON*EQUIP*LEG	9	479.053	53.228	1.27	0.304
SUBJ*EQUIP*LEG(CCON)	22	918.568	41.753		

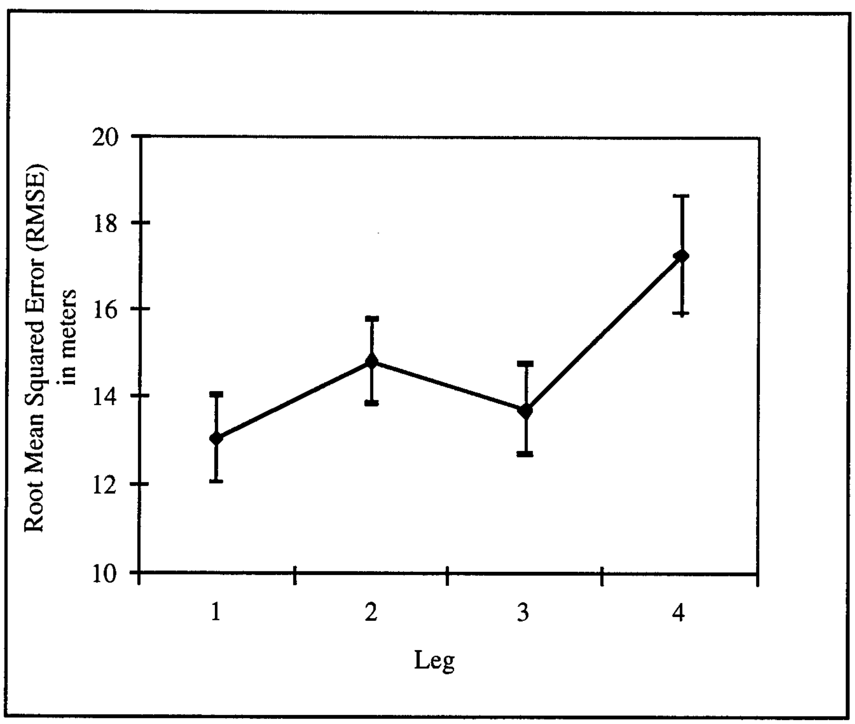

Figure 11. *Rmse* with standard errors as a function of leg.

ANOVA of Standardized Distance Traveled

Test paths A and B were each 3 km long, but the four legs within each path varied in length (i.e., 550 m, 700 m, 850 m, and 900 m). To obtain a standardized measure of performance on these different leg lengths, the actual distance traveled by the soldier was divided by the length of the leg. This allowed analysis of path leg as an independent variable. This standardized measure of distance traveled was computed for each soldier and subjected to an ANOVA similar to the one used on the *rmse* data. The results of this ANOVA are presented in Table 4.

A significant main effect was found for equipment ($F(1,8) = 5.46$, $p = .048$), where HMD-equipped soldiers traveled an average of 1.8 times the actual length of the leg, while soldiers equipped with current navigational equipment (i.e., lensatic compass, paper map, and hand-held GPS) traveled 2.26 times the distance (see Figure 12). All other effects failed to reach significance at the .05 level of confidence.

Table 4

ANOVA Results of Standardized Distance Traveled

Source	DF	ANOVA SS	Mean square	F value	Pr > F
CCON	3	1.270	0.423	0.24	0.868
SUBJ(CCON)	8	14.230	1.779		
EQUIP	1	4.324	4.324	5.46	0.048
CCON*EQUIP	3	5.193	1.731	2.19	0.168
SUBJ*EQUIP(CCON)	8	6.337	0.792		
LEG	3	3.011	1.004	1.69	0.195
CCON*LEG	9	4.610	0.512	0.86	0.568
SUBJ*LEG(CCON)	24	14.221	0.593		
EQUIP*LEG	3	1.755	0.585	1.95	0.160
CCON*EQUIP*LEG	9	3.296	0.366	1.22	0.345
SUBJ*EQUIP*LEG(CCON)	17	5.101	0.300		

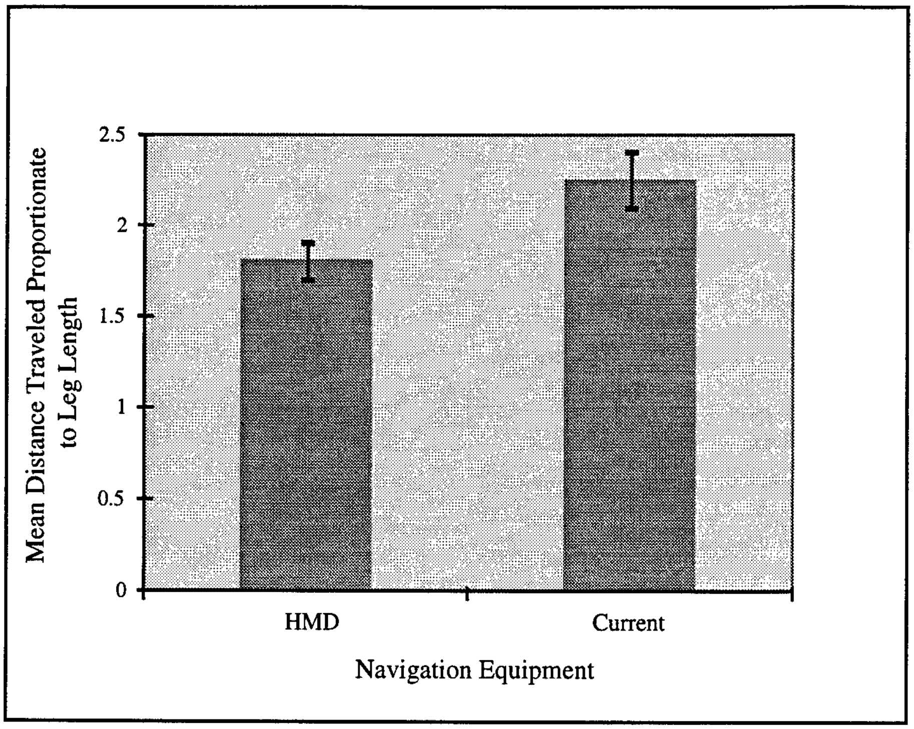

Figure 12. Average distance traveled, standardized by leg length with standard errors for HMD and current navigational equipment.

Velocity

Measures of velocity were obtained for each equipment condition by dividing the time to navigate each leg of the path by the distance the soldier traveled within the respective leg. Mean velocities were computed for each leg based on mission time and travel time. Mission time was the total time to navigate between waypoints, which included the time to perform all other mission-related tasks. Travel time was the movement time between waypoints, which excluded task time. Velocity measures based on mission and travel time were each subjected to an ANOVA.

Mission Velocity

The results of the ANOVA of mission velocity are shown in Table 5. A significant main effect was found for path leg, $F(3,24) = 3.95, p < .05$), with mean velocities of 44.51 m/min (Leg 1), 43.04 m/min (Leg 2), 36.95 m/min (Leg 3), and 44.14 m/min (Leg 4). Post hoc analyses revealed that this effect was attributable to a significant decrease in velocity between Leg 3 and Legs 1, 2, and 4 of the path (see Figure 13). The decrease in velocity in Leg 3 is attributed to greater masses of thorny vegetation which slowed movement in this leg of the path.

Table 5

ANOVA Results of Velocity (mission)

Source	DF	ANOVA SS	Mean square	F value	Pr > F
CCON	3	468.096	156.032	1.27	0.348
SUBJ(CCON)	8	982.526	122.816		
EQUIP	1	197.576	197.576	1.56	0.247
CCON*EQUIP	3	397.158	132.386	1.05	0.423
SUBJ*EQUIP(CCON)	8	1011.271	126.409		
LEG	3	869.945	289.982	3.95	0.020
CCON*LEG	9	1477.082	164.120	2.24	0.056
SUBJ*LEG(CCON)	24	1760.511	73.355		
EQUIP*LEG	3	674.964	224.988	2.93	0.055
CCON*EQUIP*LEG	9	2034.036	226.004	2.94	0.018
SUBJ*EQUIP*LEG(CCON)	23	1768.994	76.913		

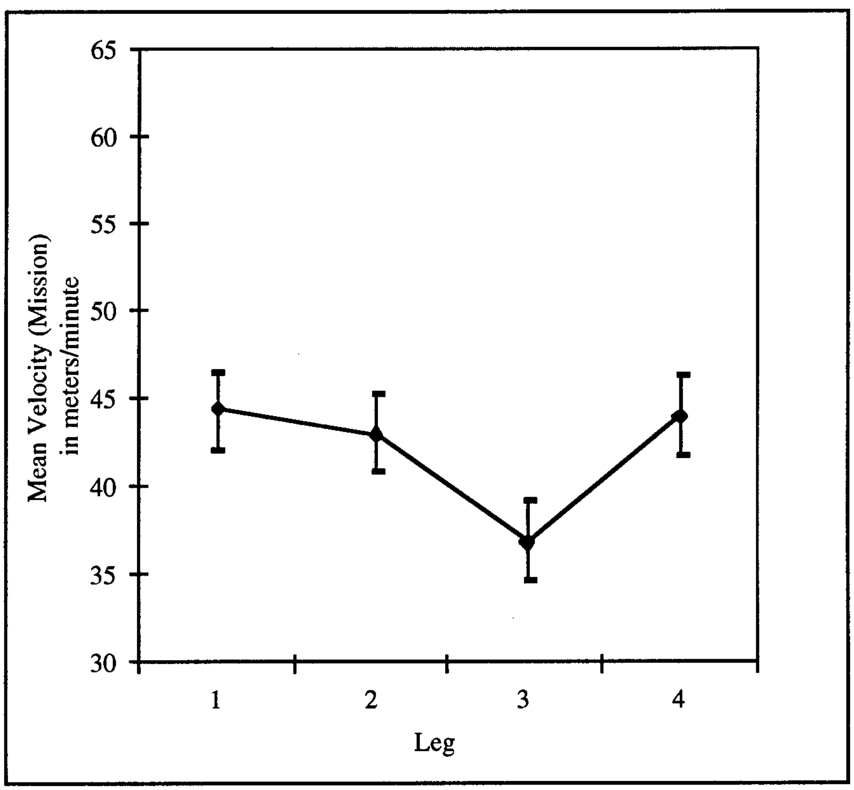

Figure 13. Mean mission velocity with standard errors by path leg.

Finally, the ANOVA also revealed a significant three-way Equipment x Path Leg x Control Variable interaction ($F(9,23) = 2.94, p < .018$). This interaction is attributed to the significantly higher velocities achieved in Leg 1 of the test path when soldiers navigated Path A first using current equipment. Velocities in subsequent legs of Path A using current equipment were significantly lower than in Leg 1, as were velocities in both equipment conditions in all legs of both test paths where equipment conditions and-or paths A and B were presented in a different order. This finding may reflect the mildness of the terrain in Leg 1 of Path A by comparison to other legs of both test paths which contained denser and sometimes thorny vegetation. It may also reflect the soldiers' premature expectations that their task would be easy, as well as their skill and confidence in navigating this milder terrain with the familiar lensatic compass. All other effects failed to reach significance at the .05 level of confidence.

Travel Velocity

The ANOVA performed on travel velocity yielded results similar to those found in the analysis of mission velocity (see Table 6). Once again, a significant effect was found for path leg, $F(3,9) = 8.14, p = .001$, with mean velocities, as depicted in Figure 14, of 56.46 m/min (Leg 1), 51.00 m/min (Leg 2), 38.81 m/min (Leg 3), and 44.17 m/ min (Leg 4). Post hoc analyses revealed that this effect was attributable to a significant decrease in velocity between Leg 1 and Legs 3 and 4 of the path, and between Leg 2 and Leg 3 of the path. This finding reflects the relative differences between path legs in terrain severity, where Leg 1 was the mildest of the legs, followed by Leg 2 and Leg 4. Leg 3 was the most difficult leg to navigate in both test paths.

Table 6

ANOVA Results of Velocity (travel)

Source	DF	ANOVA SS	Mean square	F value	Pr > F
CCON	3	936.914	312.305	1.28	0.344
SUBJ(CCON)	8	1946.111	243.264		
EQUIP	1	0.066	0.066	0.00	0.987
CCON*EQUIP	3	1192.754	397.585	1.78	0.228
SUBJ*EQUIP(CCON)	8	1784.834	223.104		
LEG	3	4225.196	1408.399	8.14	0.001
CCON*LEG	9	3381.396	375.711	2.17	0.063
SUBJ*LEG(CCON)	24	4154.664	173.111		
EQUIP*LEG	3	1652.172	550.724	2.73	0.066
CCON*EQUIP*LEG	9	5746.316	638.480	3.17	0.012
SUBJ*EQUIP*LEG(CCON)	24	4839.132	201.631		

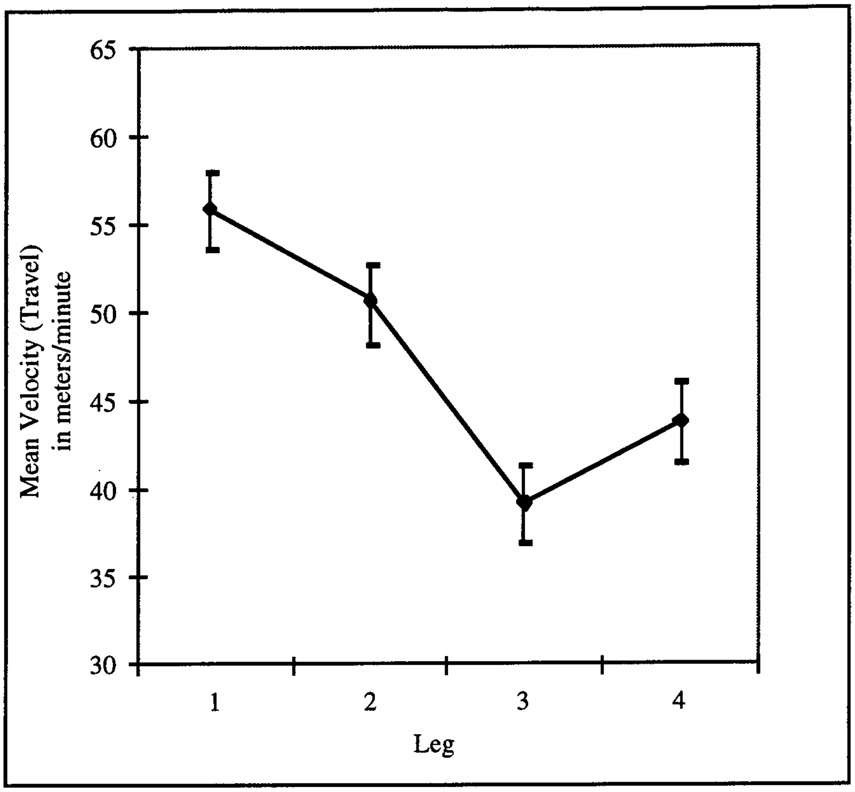

Figure 14. Mean travel velocity with standard errors by path leg.

Finally, as in the analysis of mission velocity, the ANOVA also revealed a significant three-way Equipment x Path Leg x Control Variable interaction (F (9,24) = 3.17, p = .012). Once again, this interaction is attributed to the significantly higher velocities achieved in Leg 1 of the path when soldiers navigated Path A using current equipment first. Velocities in subsequent legs of Path A using current equipment were significantly lower than in Leg 1, as were velocities in both equipment conditions in all legs of both test paths where equipment conditions and-or paths A and B were presented in a different order. All other effects failed to reach significance at the .05 level of confidence.

HMD Employment

A magnetic switch was used to determine whether the HMD was in the viewing or stowed position. However, in order to obtain a reading, it was necessary that the switch be precisely positioned. Valid data were obtained from four soldiers navigating the training path and from eight subjects navigating test paths A and B. These data are presented in Table 7.

Table 7

HMD Employment During Navigation of Training (t) and Test (A and B) Paths

Subject	Course	Percent down	Percent up	Samples (~1/sec)
1	t	32.4	67.6	9224
2	t	29.0	71.0	4920
3	t	39.1	61.0	3461
6	t	100.0	0.0	3047
1	A	4.9	95.1	7746
2	A	4.9	95.1	7732
3	B	16.2	83.8	6251
6	A	99.7	0.3	8746
7	B	20.2	79.8	7963
10	B	23.0	77.0	8640
11	A	100.0	0.0	8743
12	A	100.0	0.0	8758

Although the data are fragmentary, there are two notable trends. First, during training, the soldiers appeared to employ the HMD at least a moderate amount of the time (< 29%). Second, during testing, some soldiers employed the HMD nearly 100% of mission time while others employed it sparingly (< 5%).

HMD employment reported by the soldiers in post-test questionnaires ranged from 20% to 100% of mission time, with an average employment of 66%. This average included four soldiers who reported HMD employment 100% of mission time. Two of these four soldiers reported that they maintained the HMD in the full down position, while the other two soldiers noted that they maintained the HMD in a "semi-stowed" position. In this latter position, the soldiers noted that the HMD did not obstruct their vision and allowed them to look up to view the display.

HMD Display Format Use

Soldiers showed a clear preference for the map display and its "outside-in" perspective over the "inside-out" perspective of the rolling compass display (see Table 8). During training, the soldiers were asked to use the rolling compass display exclusively during the second of the three training trials. Nonetheless, the data suggest that, across the three trials, the soldiers predominantly relied on the map display ($\underline{M}$=91.5%, $\underline{SD}$=9.08, $\underline{N}$=12). A similar preference for the map display was shown during testing where the map view dominated mission time ($\underline{M}$=91.1%, $\underline{SD}$=14.01, $\underline{N}$=12) compared to the rolling compass ($\underline{M}$= 8.9%, $\underline{SD}$= 14.01, $\underline{N}$=12). At the conclusion of testing, when asked about their preference for the map display, the soldiers generally commented that they were more accustomed to using a map. However, deficiences in the design of the rolling compass display, as well as differences in the format of the information presented, may have had a significant influence on the soldiers' use of this display.

Table 8

HMD Display Format Use During Navigation of Training (t) and Test (A and B) Paths

Subject	Course	Map (percent)	Compass (percent)	Samples (~1/sec)
1	t	73.8	26.2	9224
2	t	89.3	10.7	4920
3	t	95.6	4.4	3461
4	t	99.1	0.8	1474
5	t	98.0	2.0	4001
6	t	98.3	1.7	3047
7	t	98.9	1.1	5446
8	t	91.5	8.5	2750
9	t	75.3	24.7	6726
10	t	94.9	5.1	6492
11	t	98.7	1.3	6994
12	t	84.7	15.3	4469
1	a	87.7	12.3	7746
2	a	96.8	3.2	7732
3	b	97.1	2.9	6251
4	b	95.9	4.1	5549
5	a	92.3	7.6	10547
6	a	64.7	35.3	8746
7	b	99.0	1.0	7963
8	b	99.8	0.2	6475
9	b	59.7	40.3	9561
10	b	100.0	0.0	8640
11	a	99.9	0.1	8743
12	a	99.9	0.1	8758

Other Mission Tasks

Detect and Identify Objects

Of the 15 objects positioned along a path, the mean number of objects detected and identified in the current equipment and HMD conditions was 6.33 (SD = 2.67) and 7.33 (SD = 2.39), respectively. Analysis indicated that there was no significant difference between equipment conditions in the performance of this task.

Determine Magnetic Azimuth

Mean times to determine magnetic azimuth in the current equipment and HMD conditions were 0.71 min (SD = 0.31) and 0.73 min (SD = 0.42), respectively. Analysis indicated that there was no significant difference between conditions in the time to perform this task.

Call for Fire

Mean times to call for fire in the current equipment and HMD conditions were 1.92 min (SD = 0.42) and 1.46 min (SD = 0.84), respectively. Analysis indicated that there was no significant difference between conditions in the time to perform this task.

Troop Movements and FRAGO

In the HMD condition, the mean time from initiation of an auditory message that alerted the soldier of a troop movement, to the time that he acknowledged the change was 0.59 min (SD = 0.17). In the current equipment condition, the mean time from initiation of the auditory message to the time that the soldier completed a manual update of the map was 3.49 min (SD = 1.48). As might be expected, differences between equipment conditions in time to complete this task were significant, $t\,(11) = 6.94, p < .001$.

In the HMD condition, the mean time from initiation of an auditory message that alerted the soldier of a change in waypoint location (FRAGO) to the time at which the soldier acknowledged this change was 0.54 min (SD = 0.22). In the current equipment condition, the mean time from initiation of the auditory message to the time that he completed a manual update of the map was 8.99 min (SD = 7.38). Again, as expected, differences between equipment conditions in time to complete this task were significant, $t\,(10) = 3.83, p = .003$.

Probe Questions and Situation Awareness

"Yes" and "no" answers to probe questions were graded as hits, false alarms, misses, or correct rejections which are defined as follows:

Hit: Answered "Yes" and "Yes" was correct
False alarm: Answered "Yes" and "No" was correct
Miss: Answered "No" and "Yes" was correct
Correct rejection: Answered "No" and "No" was correct

These scores were used to compute measures of sensitivity (d′) based on the theory of signal detection. Mean scores for the current equipment and the HMD conditions were subjected to a dependent t-test. The results of the analysis, shown in Table 9, indicate that there were no statistically significant differences between the two equipment conditions ($t(11) = .2854, p < .28$). With only a few exceptions among the soldiers, situation awareness as measured by the probe questions was poor. Mean d′s hovered around chance levels, and standard deviations were large.

Table 9

Signal Detection (d′) for Current Equipment and HMD Performance on Probe Questions

Subject	Current	HMD
1	0.854502	0.571986
2	1.82484	0.584698
3	0.841621	0.349905
4	-0.96742	1.105218
5	1.067569	1.992028
6	-0.67404	-2.26078
7	-0.55952	2.261213
8	1.240439	0.85933
9	1.28606	-0.27257
10	0.565949	1.177849
11	2.585424	2.552415
12	0.870862	3.023742
<u>M</u>=	0.74469	0.99542
<u>SD</u>=	1.040652	1.419761
	p(t)= 0.285438	correlation = 0.300592

Workload (NASA-TLX)

Weighted ratings for each of the six workload factors and an overall weighted workload score were calculated for each soldier in each equipment condition in accordance with the procedures prescribed by the NASA-TLX. Mean weighted ratings for each workload factor and the overall weighted score were computed for each condition and were analyzed using paired sample t-tests. The results of the analyses revealed a significant difference between equipment conditions in the soldiers' ratings of mental workload, t (10) = 2.175, $p < .05$. This finding is attributed to the increased mental demands imposed by some tasks on soldiers using current equipment (e.g., manual map updates).

A significant difference was also found between conditions in the overall weighted workload score, t (10) = 1.903, $p < .05$. This finding reflects the general trend toward increased workload across the six workload factors using current equipment. Figure 15 depicts the composition of the weighted workload score. In this chart, the width of each subscale bar reflects the importance (weight) of each factor derived from the soldiers' responses in pair-wise comparisons of the six factors. The height of the bars represents the magnitude (rating) of these factors derived from the soldiers' scaled ratings. The overall workload score shown to the right of the subscale bars represents the average area of these bars.

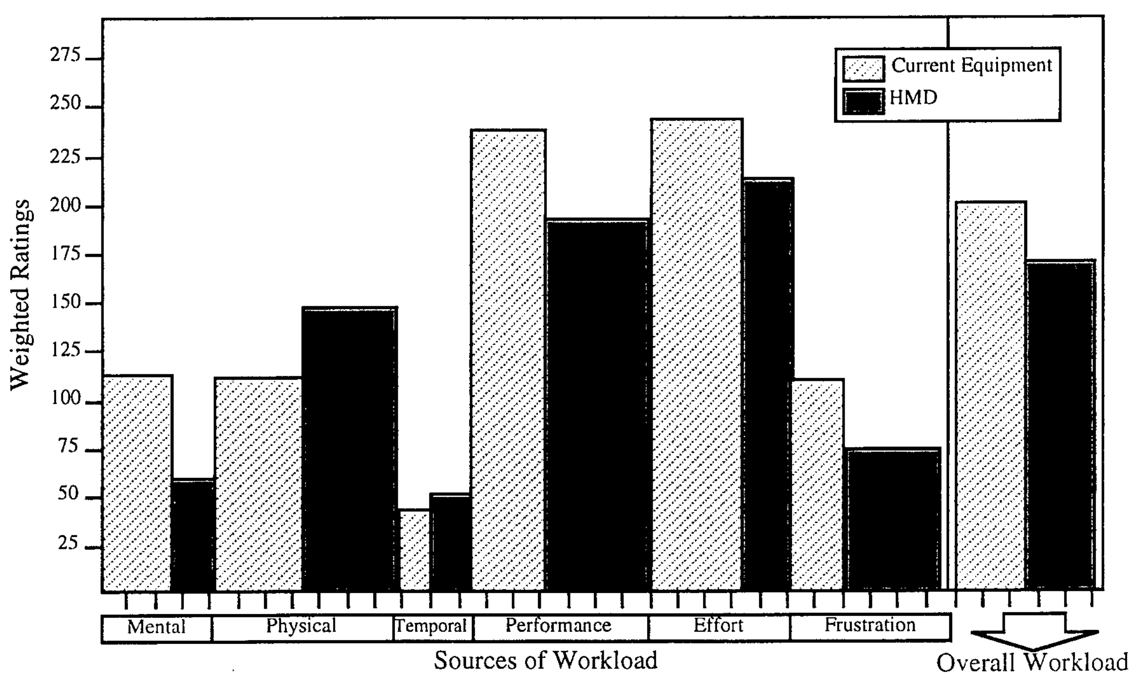

Figure 15. Mean weighted ratings of source of workload and overall workload.

Stress

Willingness, Importance, and Confidence Levels

The participants' ratings of willingness (mean = 94.17, ±SEM = 3.30) and importance (mean = 88.33, ±SEM = 3.39), indicate that they were very willing to complete the study and believed that the study was of great importance to future soldiers. The confidence levels of the participants, as measured by the Self-Efficacy scale (SES), parallels these findings, regardless of condition ($F(1,19) = .27, p = 0.659$).

Psychological Stress Levels

A three-way multivariate analysis of variance (MANOVA) (Condition x Measures x Sessions) was performed to determine if there were differences between equipment conditions across measures of psychological stress obtained using the Multiple Affect Adjective Checklist-Revised (MAACL-R). No statistically significant differences were found (Wilks' $\lambda = 0.305$; $F(7,12) = 1.324, p = 0.366$). A three-way MANOVA was also performed to determine if there were differences between conditions in measures of stress obtained using the Specific Rating of Events (SRE) scale and the Subjective Stress scale (SUBJ). No statistically significant differences were found using either of these subscales (Wilks' $\lambda = 0.093$; $F(14,3) = 0.483, p = 0.699$).

Salivary Amylase Field Test

A repeated measures ANOVA was conducted on salivary amylase across seven time points: baseline, pre HMD, during HMD, post HMD, pre current, during current, post current. Significant differences were found (Wilks' $\lambda = 0.097$; $F(6,12) = 9.22, p = 0.008$). The results of post hoc comparisons using paired t-tests indicate a significant difference between baseline and post current ($t(6,12) = -4.52, p = 0.001$) and during current and post current ($t(6,12) = -4.00, p = 0.002$). Because salivary amylase is affected by physiological as well as psychological stressors and because the results of other stress tests revealed little to no psychological stress, differences between earlier measures of salivary amylase levels and post-test measures are not attributed to an increase in mental stress but rather to an increase in physical activity imposed by manipulation of more equipment.

Cognitive Performance

Cognitive performance tasks included verbal memory, logical reasoning, addition, and spatial rotation. To delineate performance differences, each test was evaluated as to the number of items completed correctly. A separate session (pre/post) by condition (current/HMD) repeated measure ANOVA was computed for each performance variable. Baseline measures were not included in these ANOVAs. Shifts from baseline were evaluated by computing a MANOVA for each performance variable across the five sessions (baseline, pre/post measures for current and HMD conditions). One subject did not complete the baseline tests, so the MANOVAs were computed using 11 subjects.

Verbal Memory

This short-term memory test required written recall of 12 single- and double-syllable words. No significant effects were found in the ANOVA. The multivariate analysis across trials, which included the baseline measure, showed a significant difference ($F(4,40) = 3.35, p < .02$). Pair-wise comparisons indicated that the baseline measure, with a mean of 7.2, was significantly higher than for the other four trials.

Logical Reasoning

This reasoning task (Baddeley, 1968) involved 32 evaluations of two-letter pairs and a phrase describing the letter pair ordering. Each evaluation was judged as "true" or "false." Significant changes in performance were not found in the analysis of this measure.

Addition

For this computation task, soldiers were given 30 seconds to complete 15 problems of adding two randomly selected three-digit numbers together. The ANOVA did not reveal any significant effects. However, the MANOVA indicated a significant effect for trials ($F(4,40) = 5.702, p < .001$), with paired comparisons showing that baseline was significantly lower than the other four trials.

Spatial Rotation

Soldiers' performance of the spatial rotation task involved pattern recognition and figure rotation. Eighteen evaluations were presented for this task. The ANOVA indicated there was a significant main effect for trials ($F(1,11) = 5.5, p < .04$). Pair-wise comparisons indicated that the pre-test for the HMD condition (mean = 9.4) was significantly lower than post measures for current (mean = 12) and HMD (mean = 11.4) tests. No significant effects were found for the baseline analysis.

CPASE and NASA-TLX

Correlations were computed to examine the relationship between workload (as measured by the NASA-TLX) and changes in cognitive performance for each condition. The only significant correlation occurred for the HMD condition between the temporal factor of the NASA-TLX and logical reasoning, $r(10) = -0.71, p < .009$. This negative correlation indicates that as perception of temporal workload increases, the difference between pre and post scores on the logical reasoning task narrows. The expected finding would be a greater disparity between pre and post measures, with performance deteriorating at a faster rate as temporal demands increased. A better understanding of this unexpected result requires further testing.

Behavioral Anchored Rating Scales

Soldier Observations

For each question, the soldiers' scaled observations (1 to 5) were tabulated, and means computed for each question for each of the two equipment conditions. The results of paired sample t-tests revealed significant differences between conditions on 2 of 13 questions (see Table 10). Differences in the soldiers' observations relating to interference between the navigational equipment and other mission-related items favored the HMD condition, $t(11) = -2.880, p < .01$. The soldiers' observations also indicated greater interest in this new technology, $t(11) = -2.244, p < .01$. These differences reflect some of the more common concerns noted by soldiers in the post-test questionnaires related to the amount of equipment they had to carry in the current equipment condition and the soldiers' preference for the HMD.

Table 10

Results of the Analysis of Soldier Responses on Behavioral Anchored Rating Scales

	Question	Condition	Mean	df	SD	t	p
1-2b	Did the navigational equipment interfere with the soldier's ability to use other mission equipment (e.g., M16 rifle)?	Current	3.083	11	.996	-2.880	<.01
		HMD	4.250	11	1.215		
3-2b	Was the soldier interested in the navigational equipment?	Current	3.667	11	.888	-2.244	<.01
		HMD	4.250	11	.866		

Lane Walker Observations

The lane walkers' scaled observations with respect to the same questions were tabulated and analyzed in the same manner as those of the soldier. The analyses did not reveal any significant differences between equipment conditions at the .05 level of confidence.

Soldier-Lane Walker Observations

Pearson correlation analyses revealed a relationship between the soldiers' and the lane walkers' observations on 4 of the 13 questions related to current equipment, and 2 of the 13 questions related to the HMD (see Table 11). Lack of correlation between observations may reflect a deficiency in the selection and wording of some questions that precluded observation and more objective assessment.

Table 11

Results of Correlation Analysis of Soldier-Lane Walker Responses on Behavioral Anchored Rating Scales

	Issue	Condition	df	r	p
1-1a	Did the soldier have difficulty operating the navigational equipment?	Current	Soldier Lane walker	.718	<.01
1-2b	Did the navigational equipment interfere with the soldier's ability to use other mission equipment (e.g., M16 rifle)?	HMD	Soldier Lane walker	.757	<.01
1-2c	Did the navigational equipment distract the soldier when he was performing other tasks?	Current	Soldier Lane walker	.714	<.01
2-2a	Did the navigational equipment interfere with the soldier's ability to detect objects along the path?	Current	Soldier Lane walker	.867	<.01
3-1b	Was the soldier tired at the end of the path?	Current	Soldier Lane walker	.831	<.01
3-2b	Was the soldier interested in the navigational equipment?	HMD	Soldier Lane walker	.857	<.01

Soldier Preferences and Comments

Eleven of the 12 soldiers who participated in the present investigation preferred the HMD condition. The one soldier who indicated a preference for conventional navigational equipment noted that he did so because of problems he experienced with DASHER's GPS using the HMD in the first leg of the path. Generally, the soldiers noted that the HMD was "easy to use, read and follow" and that they liked the graphic displays. Two soldiers wrote that they liked everything about the HMD; and another added that "everything is provided--if the GPS is working." Two of the soldiers commented on reduced visibility using the HMD, but generally, the soldiers liked the convenience of the head-mounted display, noting that it freed their hands. In the current equipment condition, the soldiers stated that they had too much equipment to carry and manipulate with an M16 and that manual map updates were time consuming. There were frequent complaints regarding the dependability of the hand-held GPS, and some soldiers noted that, unlike the GPS, the lensatic compass "never went down."

DISCUSSION

In this study, no differences were found between equipment conditions in *rmse* deviations from the optimum or straight-line path. However, the analysis of distance traveled indicated that soldiers traveled less distance between waypoints using the HMD than they did when using conventional navigational equipment. The analysis of *rmse* deviations suggested that the soldiers deviated greater distances from path center in the last leg of the path than they did in the first three legs, but the analysis of distance traveled did not show this difference between legs. The following example indicates that distance traveled may allow a more accurate assessment of navigational accuracy.

In Figure 16, Soldier No. 1 travels 15 meters to the left of the optimum path, paralleling path center. Soldier No. 1 is either following a line of least resistance, perhaps because of an abundance of thorny vegetation, or he does not have exact knowledge of the location of the centerline of the path (e.g., GPS EPE = $\pm$20 m). Nonetheless, Soldier No. 1 is maintaining the correct azimuth toward his destination. Soldier No. 2, on the other hand, is traveling in a sinusoidal manner to the left and right of the path and may be having difficulty with the navigational equipment. When Soldier No. 2 deviates beyond prescribed limits, he is directed back to the path only to cross path centerline and deviate in the opposite direction. Although Soldier No. 1 travels nearly 40% less distance than Soldier No. 2, calculations of *rmse* deviations indicate that their accuracy in navigation is nearly equivalent.

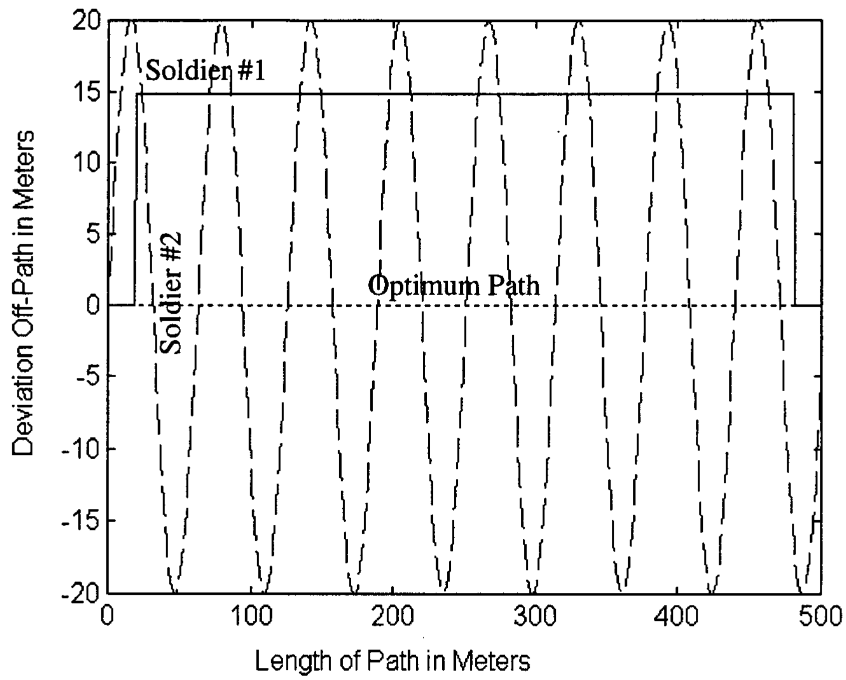

Figure 16. Sinusoidal and offset function deviation from a straight-line path (not to scale).

Differences in the results of the analysis of *rmse* deviations and distance traveled for path leg were affected by these and other factors revealed in the analyses of soldier velocity. In these analyses, no differences were found between equipment conditions in either mission or travel velocity. The expected gains in velocity affected by a reduction in the distance the HMD-equipped soldier traveled may have been nullified by the soldier's need to stop to consult the HMD's navigational displays. In the current equipment condition, soldiers could view their hand-held GPS while moving and when terrain allowed, could sustain their movement for longer distances by spotting at far points using the lensatic compass.

The analyses revealed that soldier velocity in Leg 1 of the path was significantly higher than in subsequent legs when soldiers navigated Path A using conventional navigational equipment first. This interaction may reflect a combination of factors that include the mildness of the terrain in Leg 1 of Path A by comparison to other legs of both test paths, the soldiers' skill and confidence in navigating this mild terrain with familiar equipment, and the soldiers' motivation. With the exception of Leg 1 of Path A, all legs of both test paths consisted of some briars and thickets of varying densities. By contrast, there were few briars in Leg 1 of Path A, and the trees were tall and well spaced. In this leg, soldiers using current equipment could spot at distances using the conventional lensatic compass, stopping less frequently. Vegetation progressively thickened in subsequent legs of the path, reducing visibility and perhaps any expectations that the task would be easy. To maintain the path in areas where vision at distances was reduced, the soldiers had to stop more frequently to consult their navigational equipment. Progress through sections of the path that contained briars was slower and more fatiguing. The fact that no differences were found between Leg 1 and subsequent legs of Path A when this path was navigated second may reflect the soldiers' more realistic expectations of the terrain that lay ahead and the soldiers' attempts to pace themselves.

In both equipment conditions, soldier velocity decreased significantly in Leg 3 of the path. In both paths, Leg 3 contained greater masses of thorny vegetation than the other three legs and was the most difficult leg to navigate. In this leg, path center ran between two marshy areas near which briar patches thickened and water at times was above the soldiers' boots. For safety, the soldiers were advised to adhere to the path as closely as possible to avoid more difficult terrain. The reduction in soldier velocity in Leg 3 may therefore have been artificially inflated by their attempts to heed this advice. Navigational accuracy may have also been influenced by experimenters' intervention.

Because of the thick briars in Leg 3, many soldiers had difficulty in finding Waypoint 3 (WP3), thus further decreasing measures of velocity on this leg. Upon reaching WP3, most soldiers were fatigued. However, "home" was just a leg away and there is reason to believe that the return to velocity in Leg 4 was related to the "goal box" effect where there is a tendency to accelerate when the end is near.

After Leg 3, soldiers may have been more intent on the speed at which they completed the path rather than on the accuracy with which they maintained path center. Briar patches in Leg 4 were not as dense as in Leg 3 and were more navigable. In Leg 4, vegetation progressively thinned at distances beyond 15 meters from path center. Naturally, the soldiers chose the path of least resistance. Figure 17 most clearly demonstrates the accuracy with which one soldier, using current equipment, maintained azimuth, paralleling path center and avoiding briars that would impede his progress. As demonstrated before, traveling at an offset parallel to the centerline of the path in Leg 4 would inflate the *rmse* deviation but not necessarily the actual distance the soldier traveled. However, at deviations beyond 20 meters from path center, some mission tasks that were programmed for presentation within a specific area coordinate were not initiated. This may have inflated measures of mission velocity in Leg 4.

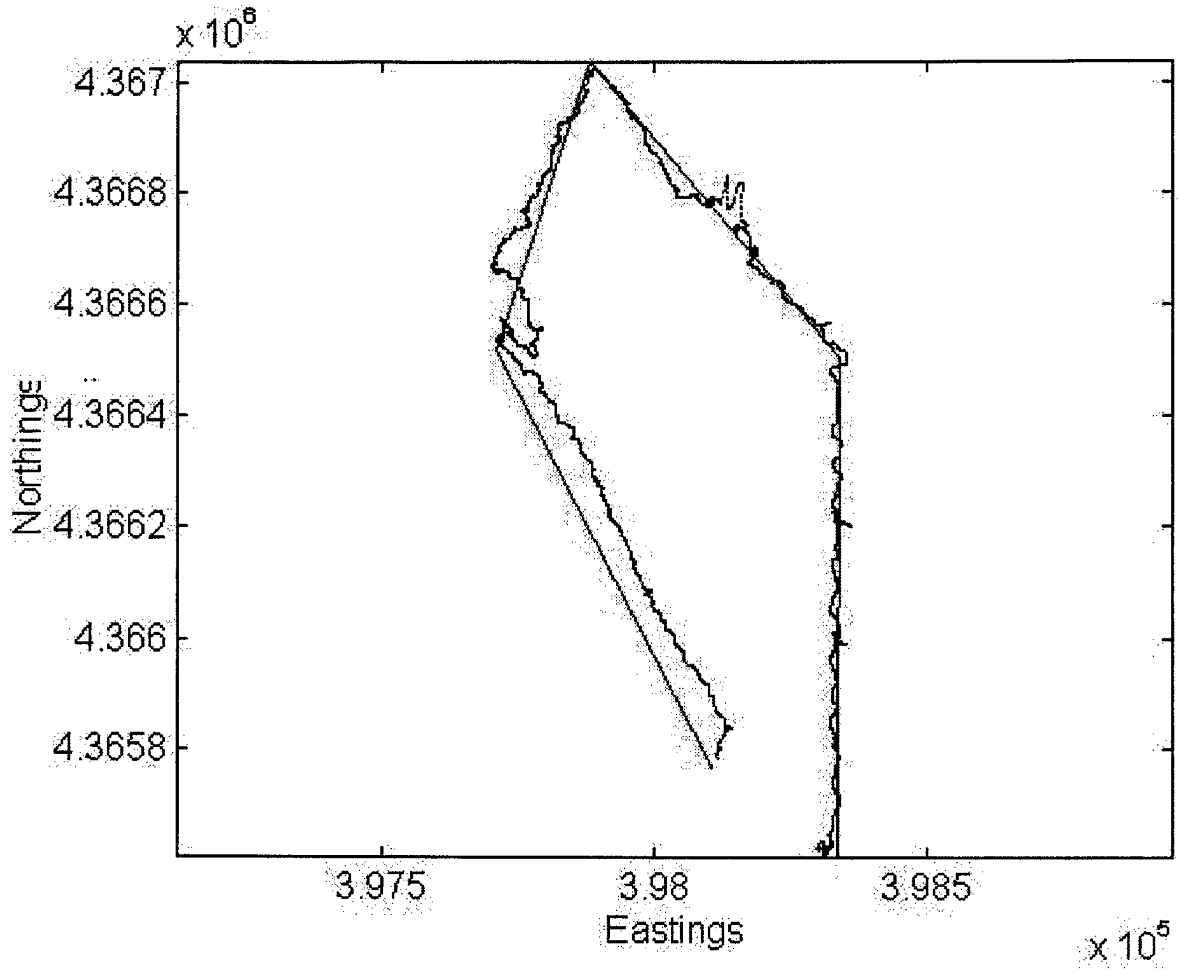

Figure 17. Soldier deviation from Leg 4 (Path A) using current equipment.

The findings of the study indicate that soldiers detected as many objects in the HMD condition as they did using conventional land navigation equipment. The lane walkers observed that, on the average, the soldiers stopped every 80 to 100 meters to view the HMD. In the current equipment condition, some soldiers frequently consulted their hand-held GPS unit while moving, closely monitoring their position with respect to the path center. In both conditions, the soldiers were observed to pass within meters of an object without detecting it. On a number of occasions, soldiers stopped momentarily to examine their hand-held or head-mounted displays, unaware of an object within a few meters of their position. One soldier using current equipment stopped directly on a land mine, unaware of its presence until he stepped off.

In this study, no differences were found between conditions in time to perform other mission-related tasks (i.e., determine magnetic azimuth and call for fire). However, in the current equipment condition, manual map updates to note changes in unit position and waypoint destination consumed more time by comparison to the HMD condition where such changes were displayed automatically.

The soldiers' overall ratings of workload, as measured by the NASA-TLX, were significantly higher using current navigational equipment than using the HMD system. In the calculation of these overall ratings, the ratings of those workload factors that contributed most to the soldier's workload experience are given more weight, thus enhancing the sensitivity of this measure. The reduction in overall workload in the HMD condition reflects the advantages of the system that are supported by the soldiers' preference for the HMD and related comments (i.e., "freed my hands," "easy to read and follow," "everything was provided"). The soldiers' performance and the level of effort they expended to attain this performance appeared to have the greatest influence on the soldiers' workload experience in both equipment conditions; however, in the analyses of differences between each of the six workload factors, the only difference found between conditions was in the area of mental demands. This latter finding reflects the interpretability of the display as well as differences in the level of automation between current equipment and the HMD system which may have impacted the amount of mental processing required to perform some mission tasks.

The results of the analyses of the psychological stress perception measures indicated little or no psychological stress associated with either experimental condition. However, the results of the Salivary Amylase Field Test indicated that, in the current equipment condition, differences between earlier measures of salivary amylase and post-test measures were significant. Because salivary amylase is affected by physiological as well as psychological stressors and because the results of other stress tests revealed little to no psychological stress, differences between salivary amylase measures in the current equipment condition are not attributed to an increase in mental stress but rather to an increase in physical activity imposed by manipulation of more equipment.

No differences were found between conditions in cognitive performance. In the HMD condition, however, post performance scores on Spatial Rotation were unexpectedly higher than pre-measure scores. This finding is attributed to the practice the soldiers received in mentally rotating the HMD's map display that was fixed in the north-up direction. Generally, differences were also found between baseline and post measures for Word Recall and Addition. As expected, performance was significantly higher for the baseline measure of Word Recall. However, baseline scores were significantly lower than the post measure for the Addition task. As for Spatial

Rotation, this latter finding is attributed to practice effects. In both the HMD and current equipment conditions, soldier tasks involved mental math.

Situation awareness, as measured by probe questions, was not significantly affected by test condition. Although it might seem intuitive that having information constantly available on an HMD would increase awareness, this did not appear to be the case. Data obtained about HMD employment, although fragmentary, indicate that many of the soldiers maintained the display in the stowed position 75% or more of mission time. Even then, when soldiers stopped to view their HMD, it is suspected that they were more focused on navigational information. On these occasions, the soldiers may not have paid close attention to their position with respect to other units or terrain landmarks even though they were fully aware that their knowledge of the situation would be frequently tested.

In the current equipment condition, the lensatic compass and the hand-held GPS supplied the soldiers all the information needed to maintain their path between waypoints. It was observed that the soldiers seldom attended to their paper map except during map updates or at times to verify the accuracy of their response to a probe question. In the current equipment condition, the soldiers' hands were already overburdened, and they were less inclined to stop to retrieve the map from their pocket. However, despite the rationale that may explain the lack of difference between the two equipment conditions using this measure of situation awareness, there are problems that can occur in the administration and response to probe questions that cannot be ascertained from the data. Further assessment of this technique is required to determine its effectiveness as a measure of situation awareness.

In the HMD condition, the soldiers showed a clear preference for the map display and its outside-in perspective over the inside-out perspective of the rolling compass. The map display leveraged considerable transfer of training from the current method and was easy to use. Although soldiers stated that they were more accustomed to using a map, it is possible that deficiences in the design of the rolling compass display may have had a significant influence on its usage. The rolling compass did not depict terrain features or landmarks, nor did it provide a 360° perspective of the battlefield, and unit positions beyond its 180° field of view were not readily interpreted. Although the rolling compass display was used less often than the map display, these deficiences could have potentially impacted the accuracy of the soldiers' response to probe questions.

Understanding the findings of this navigational experiment requires a perspective on the method and its limits. Testing the effectiveness of helmet-mounted navigational displays is necessarily confounded by the proficiency and motivation of the military participants and the tested system's particular implementation. Training was identified early as crucial in the evaluation, and considerable attention was devoted to ensuring soldier proficiency using both the HMD and current navigational equipment. If training did exert some influence on the outcome of the study, however, it is expected that the bias would favor the more familiar, conventional tools of navigation. Then, the improvements measured using the HMD system in this study would be conservative estimates of that system's advantage.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this investigation appear to indicate that the effective integration of navigational information on an HMD can measurably enhance navigational efficiency by providing the soldier readily accessible and easily interpretable information on his or her position. Although the reduction in the distance traveled by the HMD-equipped soldier did not bring about the expected increase in his velocity, greater efficiency in navigating from point to point can potentially result in lower levels of fatigue and improved performance upon arrival at the soldier's destination. Significant reductions in the soldier's mental workload, as well as a decrease in the soldier's overall workload experience, are also achievable using an HMD. However, it is important to note that, although the findings of this study appear to favor the HMD, results could possibly differ with other display formats and increases in the quantity of information displayed. Whether these advantages in performance and reduced workload using the HMD are attributable to the effective integration of displayed information, head-mounting of the displays, or both, remains uncertain.

The present field experiment validates the concept that objective data can be collected by the same apparatus that is acting as the evaluation system. Employing relatively low-cost mimic systems based on commercial off-the-shelf components can provide valuable part-task information for the development of specialized hardware and software such as the Land Warrior soldier electronics suite.

In this study, the precision code GPS was accurate enough to identify soldier position. The DASHER map display had a 4-meter/pixel resolution, and jitter that was attributable to fluctuations in GPS accuracy was not noticeable unless the receiver lost lock and a large drift occurred. Initial concerns about the use of P(Y)-GPS to evaluate navigational performance were partially alleviated. Post-processing the raw data by filtering with a moving average dramatically improved accuracy. Accuracy may be further improved by adding a dead-reckoning system to dampen GPS drift. This means that field research can be conducted anywhere without the expense of differential GPS base stations, allowing data collection in conjunction with field exercises such as those at the National Training Center or base ranges.

The next generation DASHER system will support a 4- to 6-inch wearable flat panel display. An ensuing study might compare helmet-mounted and body-mounted displays to determine whether HMD costs are justified by a performance advantage. Current research plans are to examine trade-offs between visually and auditorially displayed information that can be implemented for both conventional equipment as well as HMD technology. Auditory cues, for example, could be used to indicate the position of other tactical units or the soldier's position with respect to the optimum path, thus off-loading the visual channel. Further research is needed to define the soldier's information requirements and the format in which this information should be presented. Field experimentation is required to quantify the impact of these new display technologies and techniques on individual soldier and higher unit performance in the environment within which this equipment will be used.

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APPENDIX A

DEMOGRAPHIC QUESTIONNAIRE

Subject No.: _______

DEMOGRAPHIC QUESTIONNAIRE

Please answer the following questions. The information you provide will be kept <u>*CONFIDENTIAL.*</u>

1. Name: ____
   Last First Middle Initial

2. Age: __________

3. Rank: ________________

4. Military Occupational Specialty (MOS): ______________

5. Time in Service: ______years _______ months

6. Time in grade: _______years _______ months

7. Time in MOS: _______years _______ months

8. Are you left- or right-handed?

   Left-Handed [ ] Right-Handed [ ]

9. Do you wear eyeglasses or contacts?

   Yes [ ] No [ ]

10. Have you ever worn a head- or helmet-mounted display (HMD)?

    Yes [ ] No [ ]

11. How would you rate your ability to use a lensatic compass?

Excellent	[ ]
Good	[ ]
Neither Good nor Bad	[ ]
Fair	[ ]
Poor	[ ]
Never used one	[ ]

12. How would you rate your ability to use a hand-held Global Positioning System (GPS)?

Excellent	[ ]
Good	[ ]
Neither Good nor Bad	[ ]
Fair	[ ]
Poor	[ ]
Never Used One	[ ]

13. Generally, how would you rate your land navigation skills?

Excellent	[ ]
Good	[ ]
Neither Good nor Bad	[ ]
Fair	[ ]
Poor	[ ]

APPENDIX B

SALIVARY AMYLASE FIELD TEST AND STRESS QUESTIONNAIRES

SALIVARY AMYLASE FIELD TEST

Amylase is an enzyme that hydrolyzes starch to oligosaccharides and then slowly to maltose and glucose. Measurement of amylase in saliva involves chemical color changes according to standard photometric procedures developed by Northwestern University (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996). This method combines time lapse and temperature data to derive a quantifiable level of stress.

A saliva sample is obtained from a soldier using a small, clean rectangular sponge (1 in. x .5 in. x .5 in). The sponge is contained in a pre-labeled plastic cup with lid. The soldier is instructed to remove the sponge from the cup and roll the sponge in his or her mouth for 1 minute. Then, upon instruction, the soldier is asked to place the sponge back in the cup, close the lid, and hand the cup to the monitor. The cup containing the sponge is then placed in an insulated bag with an ice pack or refrigerated, as needed, to keep the sample cold for later assay.

References:

Chatterton, R.T., Vogelsong, K.M., Lu, Y., Ellman, A.B. & Hudgens, G.A. (1996). Salivary amylase as a measure of endogenous adrenergic activity. Clinical Psychology, 16.

STRESS QUESTIONNAIRES

A select battery of state questionnaires used in previous ARL research investigations was administered to the HMD subjects (Fatkin, King, & Hudgens, 1990; Hudgens, Malkin, & Fatkin, 1992; Blewett, O'Hern, Harris, Redmond, Fatkin, Rice, & Popp, 1994; Fatkin & Hudgens, 1994; Fatkin, Treadwell, Knapik, Patton, Mullins, & Swann, 1997). This battery has proven sensitive to the degree of stress experienced in a variety of situations and includes standardized measures that have demonstrated construct validity within the stress research literature. A description of the questionnaires in this battery and their administration in the present study follow.

Motivation Levels. Importance and willingness measures were collected on the day in which baseline measures were obtained. The participants were asked to rate on a scale from 0-100 the importance of successfully completing the study, and their willingness to participate in all aspects of the study.

The Self-Efficacy Scale (SES) was administered before each test run. This scale asks respondents to rate their level of confidence on a scale of 1-10 in their ability to do well with reference to anticipation of "today's experiences." Positive correlations have been obtained between self-efficacy and vocational, educational and military success (Sherer et al, 1982; Bandura, 1977; Hudgens, Malto, Geddie, & Fatkin, 1991).

The following measures were obtained before, during, and immediately after a test run:

Multiple Affect Adjective Check List -Revised (MAACL-R) . Because of the improved discriminant validity and the control of the checking response set, the MAACL-R with its five subscales -- anxiety, depression, hostility, positive affect and negative affect -- has been particularly suitable for investigations that postulate changes in specific affects in response to stressful situations. The participants were instructed to answer according to how they feel "right now" or how they felt during a specific time period or event (Zuckerman & Lubin, 1985).

The Subjective Stress Scale (SUBJ) was developed to detect significant affective changes in stressful conditions. The participants were instructed to select one word from a list of 15 adjectives that describe how they feel "right now" or how they felt during a specific time period or event (Kerle and Bialek, 1958).

The Specific Rating of Events Scale (SRE) is a measure designed for the ARL stress program in which the participants rate (on a scale of 0 for "not at all stressful" to 100 for "most stress possible") how stressed they feel "right now" or how stressful an event or time period was to them (Fatkin, King, & Hudgens, 1990).

References:

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84, 191-215.

Blewett, W.K., O'Hern, M., Harris, L., Redmond, D.P., Fatkin, L.F., Rice, D.J., & Popp, K. (1994). A P2NBC2 report: Patient decontamination at mobile medical facilities. Aberdeen Proving Ground, MD: Edgewood Research, Development, and Engineering Center.

Fatkin, L.T., & Hudgens, G.A. (1994). Stress perceptions of soldiers participating in training at the Chemical Defense Training Facility: The mediating effects of motivation, experience, and confidence level (ARL-TR-365). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Fatkin, L.T., King, J.M., & Hudgens, G.A. (1990). Evaluation of stress experienced by Yellowstone Army fire fighters (ARL-TM 9-90). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Hudgens, G.A., Malto, B.O., Geddie, J.C., & Fatkin, L.T. (1991). Stress evaluation for the TOW Accuracy Study (TN No. 5-91). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

Kerle, R.H., & Bialek, H. M. (1958). The construction, validation, and application of a Subjective Stress Scale (Staff Memorandum Fighter IV, Study 23). Presidio of Monterey, CA: US Army Leadership Human Research Unit.

Sherer, M., Maddux, J.E., Mercandante, B., Prentice-Dunn, S., Jacobs, B., & Rogers, R.W. (1982). The self-efficacy scale: Construction and validation. Psychological Reports, 51, 663-671.

Zuckerman, M., & Lubin, B. (1985). Manual for the Multiple Affect Adjective Check List-Revised. San Diego, CA: Educational and Industrial Testing Service.

LIFE EVENTS FORM II

1. Check the appropriate response: "Since I last completed these questionnaires, I have experienced:"

   Unusually low stress ______
   Mild stress ______
   Moderate stress ______
   High stress ______
   Unusually high stress ______

2. How would you rate the way you handled these events?

   Very well ______
   Well ______
   Adequate ______
   Poorly ______
   Very poorly ______

3. On the scale below, place a mark on the line to indicate how important the completion of the study requirements are to you.

   0 10 20 30 40 50 60 70 80 90 100

   not important at all — **extremely important**

   Please explain why: ____

4. On the scale below, please rate how willing you are to participate in this study.

   0 10 20 30 40 50 60 70 80 90 100

   not at all — **very willing**

MULTIPLE AFFECT
ADJECTIVE CHECK LIST

DIRECTIONS: On the next sheet you will find words which describe different kinds of moods and feelings. Mark an **X** in the boxes beside the words which describe how you feel **right now**. Some of the words may sound alike, but we want you to check all the words that describe your feelings. Work rapidly.

MULTIPLE AFFECT ADJECTIVE CHECK LIST

DIRECTIONS: On the next sheet you will find words which describe different kinds of moods and feelings. Mark an **X** in the boxes beside the words which describe how you felt **while completing the training**. Some of the words may sound alike, but we want you to check all the words that describe your feelings. Work rapidly.

PA SS

1 ☐ active
2 ☐ adventurous
3 ☐ affectionate
4 ☐ afraid
5 ☐ agitated
6 ☐ agreeable
7 ☐ aggressive
8 ☐ alive
9 ☐ alone
10 ☐ amiable
11 ☐ amused
12 ☐ angry
13 ☐ annoyed
14 ☐ awful
15 ☐ bashful
16 ☐ bitter
17 ☐ blue
18 ☐ bored
19 ☐ calm
20 ☐ cautious
21 ☐ cheerful
22 ☐ clean
23 ☐ complaining
24 ☐ contented
25 ☐ contrary
26 ☐ cool
27 ☐ cooperative
28 ☐ critical
29 ☐ cross
30 ☐ cruel
31 ☐ daring
32 ☐ desperate
33 ☐ destroyed
34 ☐ devoted
35 ☐ disagreeable
36 ☐ discontented
37 ☐ discouraged
38 ☐ disgusted
39 ☐ displeased
40 ☐ energetic
41 ☐ enraged
42 ☐ enthusiastic
43 ☐ fearful
44 ☐ fine
45 ☐ fit
46 ☐ forlorn
47 ☐ frank
48 ☐ free
49 ☐ friendly
50 ☐ frightened
51 ☐ furious
52 ☐ lively
53 ☐ gentle
54 ☐ glad
55 ☐ gloomy
56 ☐ good
57 ☐ good-natured
58 ☐ grim
59 ☐ happy
60 ☐ healthy
61 ☐ hopeless
62 ☐ hostile
63 ☐ impatient
64 ☐ incensed
65 ☐ indignant
66 ☐ inspired
67 ☐ interested
68 ☐ irritated
69 ☐ jealous
70 ☐ joyful
71 ☐ kindly
72 ☐ lonely
73 ☐ lost
74 ☐ loving
75 ☐ low
76 ☐ lucky
77 ☐ mad
78 ☐ mean
79 ☐ meek
80 ☐ merry
81 ☐ mild
82 ☐ miserable
83 ☐ nervous
84 ☐ obliging
85 ☐ offended
86 ☐ outraged
87 ☐ panicky
88 ☐ patient
89 ☐ peaceful
90 ☐ pleased
91 ☐ pleasant
92 ☐ polite
93 ☐ powerful
94 ☐ quiet
95 ☐ reckless
96 ☐ rejected
97 ☐ rough
98 ☐ sad
99 ☐ safe
100 ☐ satisfied
101 ☐ secure
102 ☐ shaky
103 ☐ shy
104 ☐ soothed
105 ☐ steady
106 ☐ stubborn
107 ☐ stormy
108 ☐ strong
109 ☐ suffering
110 ☐ sullen
111 ☐ sunk
112 ☐ sympathetic
113 ☐ tame
114 ☐ tender
115 ☐ tense
116 ☐ terrible
117 ☐ terrified
118 ☐ thoughtful
119 ☐ timid
120 ☐ tormented
121 ☐ understanding
122 ☐ unhappy
123 ☐ unsociable
124 ☐ upset
125 ☐ vexed
126 ☐ warm
127 ☐ whole
128 ☐ wild
129 ☐ willful
130 ☐ wilted
131 ☐ worrying
132 ☐ young

SUBJECTIVE SCALE

Circle ONE word that best describes how you feel right now.

Wonderful

Fine

Comfortable

Steady

Not Bothered

Indifferent

Timid

Unsteady

Nervous

Worried

Unsafe

Frightened

Terrible

In Agony

Scared Stiff

RATING OF EVENTS - SPECIFIC

1. The scale below represents a range of how stressful an event might be. Put a check mark touching the line (✓) to rate how much stress you are experiencing right now.

Not at All Stressful	**Most Stress Possible**

0 10 20 30 40 50 60 70 80 90 100

2. At what number value does the check mark touch the line? ________

SSE

1. **On a scale from 1 to 10, how confident are you in your ability to deal with today's experiences? Please circle one of the numbers below.**

1	2	3	4	5	6	7	8	9	10
Not at all confident									Extremely confident

APPENDIX C

COGNITIVE PERFORMANCE ASSESSMENT FOR STRESS AND ENDURANCE (CPASE)

COGNITIVE PERFORMANCE ASSESSMENT FOR STRESS AND ENDURANCE (CPASE)

CPASE (Mullins, 1996) is administered in a paper and pencil format and emphasizes speed and accuracy in completion of the following test measures:

Verbal Memory. The short-term memory test uses lists taken from a word usage text (Thorndike & Lorge, 1944). Each list consists of twelve one- or two-syllable words with the most common usage rating (100 or more per million). Soldiers are given one minute to study the list and one minute for recall.

Logical Reasoning. The reasoning test evaluates an understanding of grammatical transformations on sentences of various levels of syntactic complexity (Baddeley, 1968). Each item consists of a true or false statement such as "A follows B----AB" (false) or "B precedes A----BA" (true). The test is balanced for the following conditions: positive versus negative, active versus passive, precedes versus follows, order of statement letter presentation, and order of letters in the pair (equivalent to balancing for true or false condition). Letter pairs are selected to minimize acoustic and verbal confusion. One minute is given to complete the 32 evaluations.

Addition. This task, adapted from Williams and Lubin (1967), tests working memory. Each calculation consists of a pair of three-digit numbers which are selected from a random number table. The task is subject-paced. Soldiers have 30 seconds to complete as many of the 15 problems as possible.

Spatial Rotation. Spatial ability is tested using a mental rotation task adapted from Shepherd's work (1978). A six-by-six grid is enclosed within a hexagon measuring 2.8 centimeters across the diameter. Portions of the grid are blackened to create random patterns. To the right of each test pattern are three similar patterns. One of the three patterns is identical to the test pattern except that it has been rotated. The task is to select this pattern. Each test consists of eighteen items balanced for the number of grids blackened (7, 9, or 11), pattern density (adjacent blocks blackened versus a break between blocks), and rotation of the correct answer (90, 180, or 270 degrees). Two minutes are given to complete the 18 evaluations.

Copies of the above-described CPASE test battery follow.

References:

Baddeley, A. (1968). A 3-minute reasoning task based on grammatical transformation. Psychonomic Science, 10, 341-342.

Mullins, L.L. (1996, draft). Cognitive performance assessment for stress endurance (CPASE). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Shepard, R.N. (1978). The mental image. American Psychologist, 33, 125-137.

Thorndike, E.L., & Lorge, I. (1944). The teacher's work book of 30,000 words. New York: Columbia University.

Williams, H.L., & Lubin, A. (1967). Speeded addition and sleep loss. Journal of Experimental Psychology, 73(2), 313-317.

WORD RECALL TASK

INSTRUCTIONS: You will receive a page with of a list of twelve words. Keep this list face down until you are instructed to start the test. Read through the list and write each word in the recopy column as quickly as possible. You will have one minute to write and study the words. You will be asked to recall these words later in the session.

Do not turn to the next page until instructed to do so.

Word List	Recopy
law	______________________
free	______________________
flower	______________________
going	______________________
happy	______________________
sweet	______________________
friend	______________________
window	______________________
man	______________________
fresh	______________________
spring	______________________
paper	______________________

List 1

Word Recall Task

List 1

LOGICAL REASONING
INSTRUCTIONS

In the following test there are a number of short sentences each followed by a pair of letters. The sentences claim to describe the order of the two letters. Your task is to read each sentence and to decide whether it is a true or false description of the letter pair which follows it. If you think the sentence describes the letter pair correctly circle True. If you think the sentence does not describe the letter pair correctly then circle False.

EXAMPLES

1.	A follows B	AB	True (False)
2.	B precedes A	BA	(True) False
3.	A is followed by B	BA	True (False)
4.	B is not followed by A	AB	(True) False
5.	B is preceded by A	AB	(True) False

When you start the main test, work as quickly as you can without making mistakes. Start with sentence 1 and work systematically through the test without skipping any items. You will have one minute to complete as many of the statements as possible.

1AB

1.	A does not follow B	AB	True	False
2.	A does not precede B	BA	True	False
3.	B does not follow A	BA	True	False
4.	A precedes B	AB	True	False
5.	A is not preceded by B	BA	True	False
6.	B is not preceded by A	BA	True	False
7.	B precedes A	BA	True	False
8.	B is not followed by A	BA	True	False
9.	B does not follow A	AB	True	False
10.	B is not preceded by A	AB	True	False
11.	B is not followed by A	AB	True	False
12.	A precedes B	BA	True	False
13.	A is not followed by B	AB	True	False
14.	A follows B	BA	True	False
15.	B is preceded by A	BA	True	False
16.	A follows B	AB	True	False
17.	A does not follow B	BA	True	False
18.	A is preceded by B	BA	True	False
19.	B does not precede A	AB	True	False
20.	B follows A	BA	True	False
21.	A is followed by B	AB	True	False
22.	A is preceded by B	AB	True	False
23.	A is followed by B	BA	True	False
24.	B does not precede A	BA	True	False
25.	A is not preceded by B	AB	True	False
26.	A does not precede B	AB	True	False
27.	B is followed by A	BA	True	False
28.	B precedes A	AB	True	False
29.	B is followed by A	AB	True	False
30.	B is preceded by A	AB	True	False
31.	A is not followed by B	BA	True	False
32.	B follows A	AB	True	False

Add the Following Numbers Together

104 223	289 635	486 541
241 421	429 365	326 293
792 956	119 185	248 815
789 523	368 111	296 742
698 743	521 705	472 851

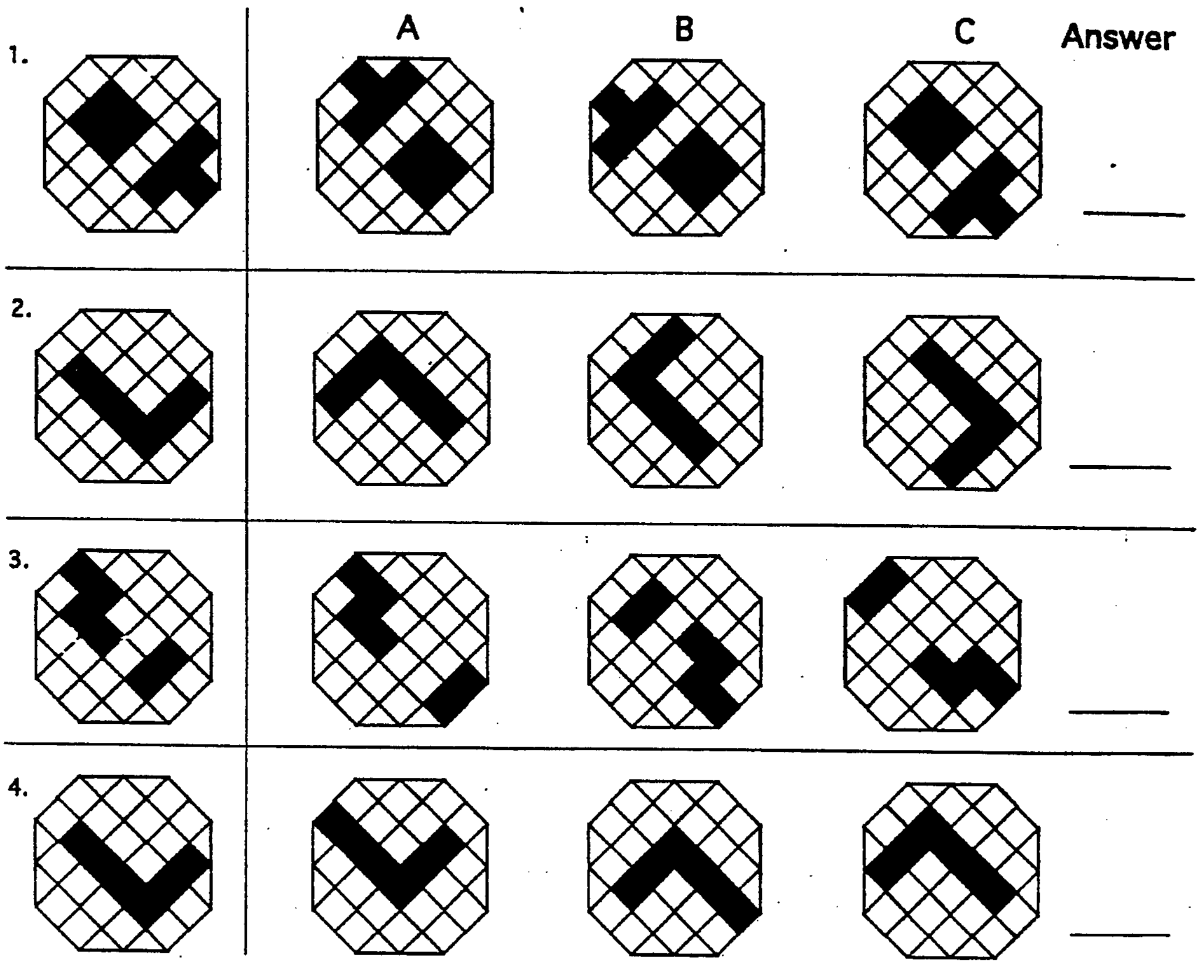
1

Spatial Rotation Task

Instructions: This task consists of rotated patterns. To the right of each pattern there are three similar patterns. One of the three patterns on the right is identical to the pattern to the left except it has been rotated clockwise by 90, 180, or 270 degrees. Pick the pattern that is like the one on the left and write the answer (A, B, or C) to the right in the space provided. Work through the problems in the order they are presented. Do Not Skip Items.

Be careful not to select an item that is a mirror image, or that has been shifted within the frame.

Examples:



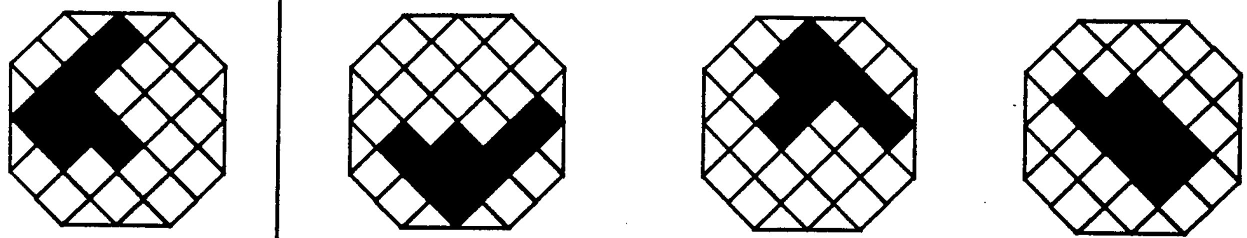
Example 1: The correct answer is B. A and C are incorrect because they are mirror images of the original item.

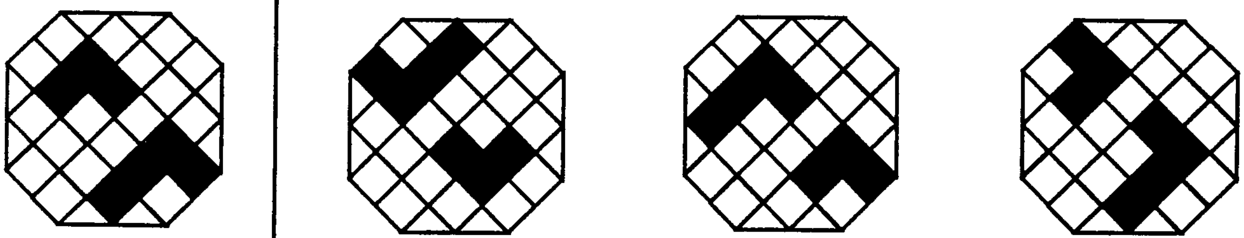
Example 2: The correct answer is A. Again B and C are mirror images of the original item.

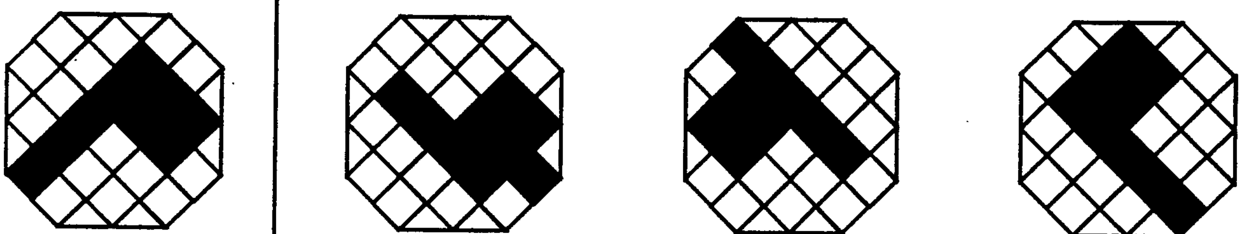
Example 3: The correct answer is B. Note that A and C are incorrect because the 2 block section is shifted to the outer edge of the frame.

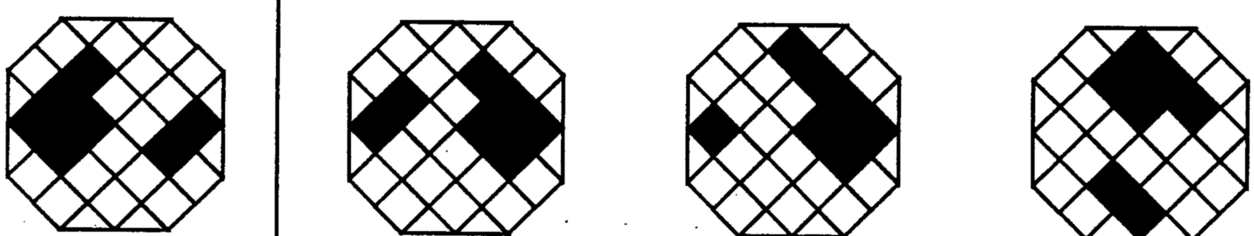
Example 4: The correct answer is C. A and B are incorrect because the shape is shifted within the frame.

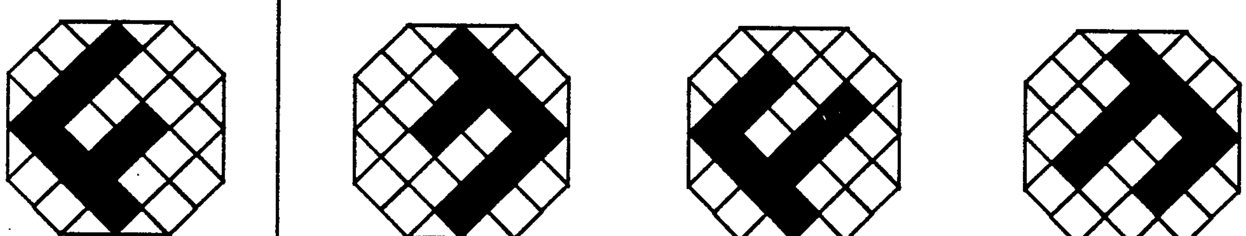
A **B** **C** **Answer**

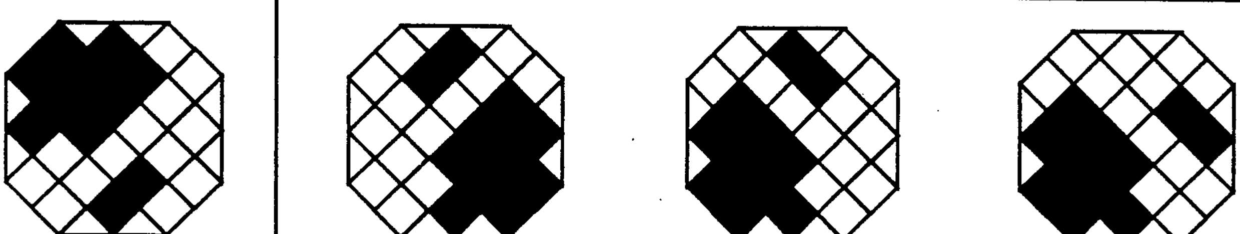


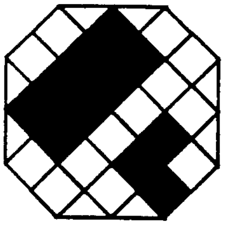
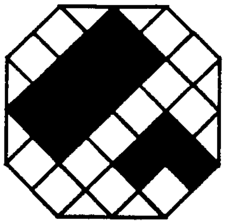
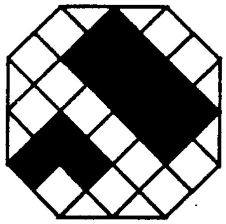
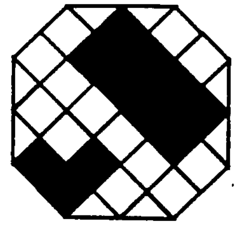
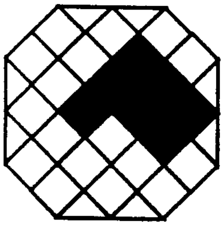
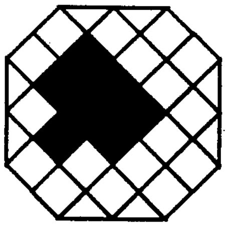
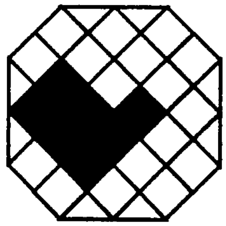
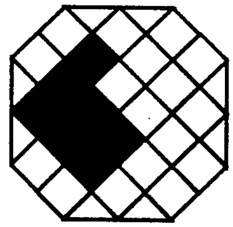
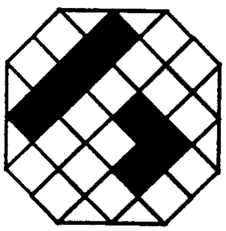
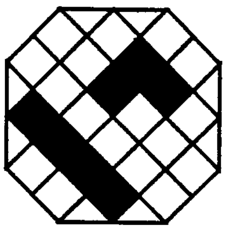
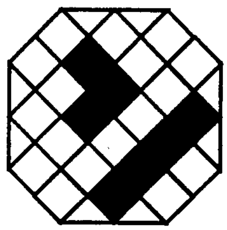
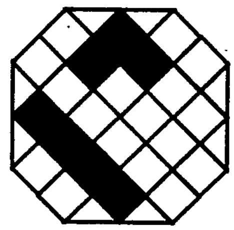
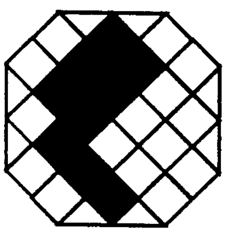
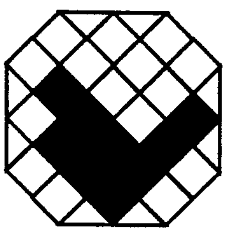
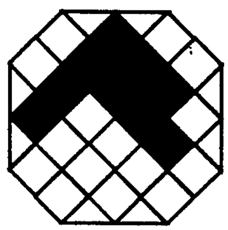
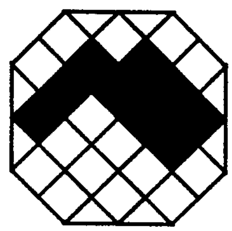
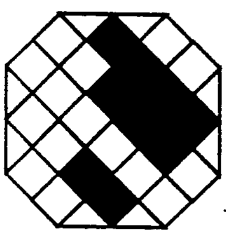
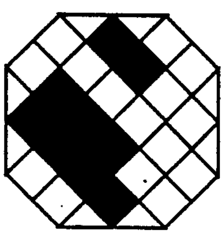
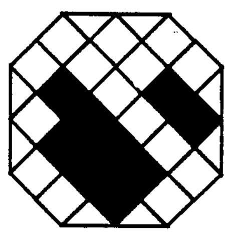
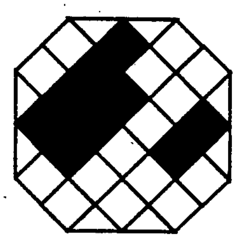
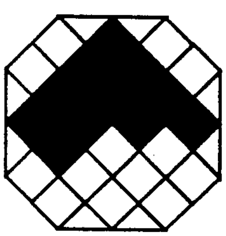
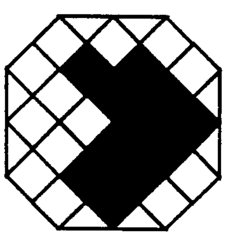
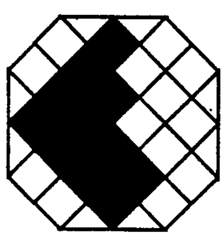
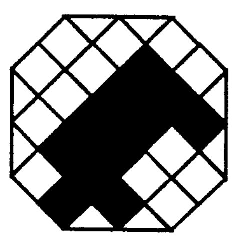




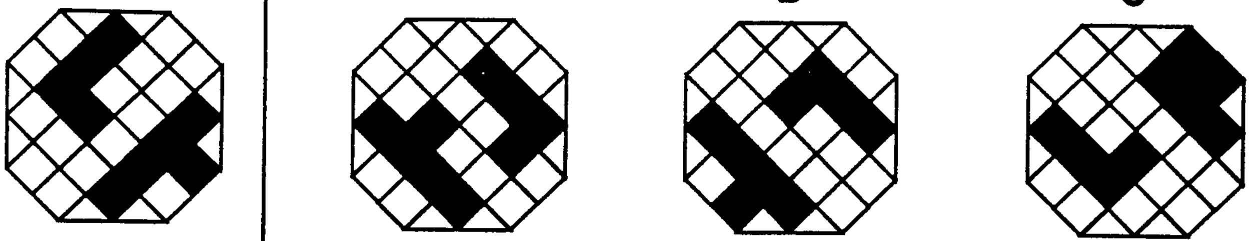






	A	B	C	Answer
				
				
				
				
				
				

	A	B	C	Answer



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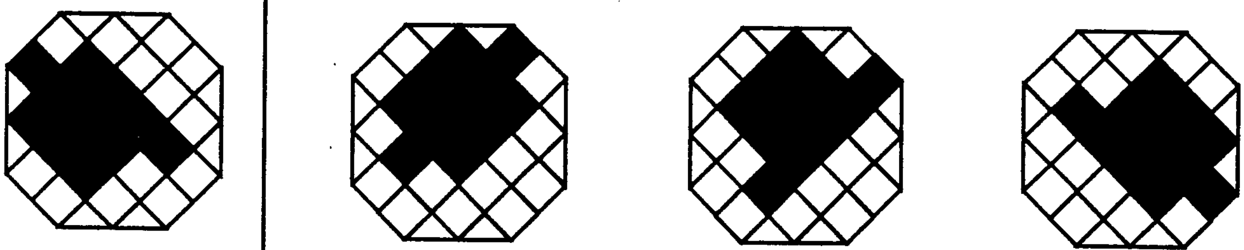

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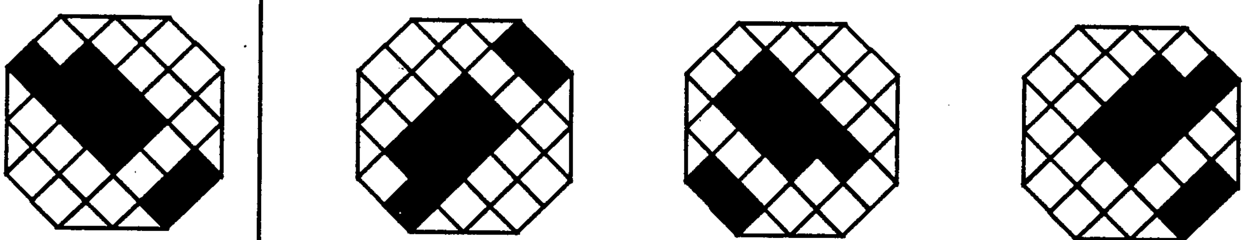

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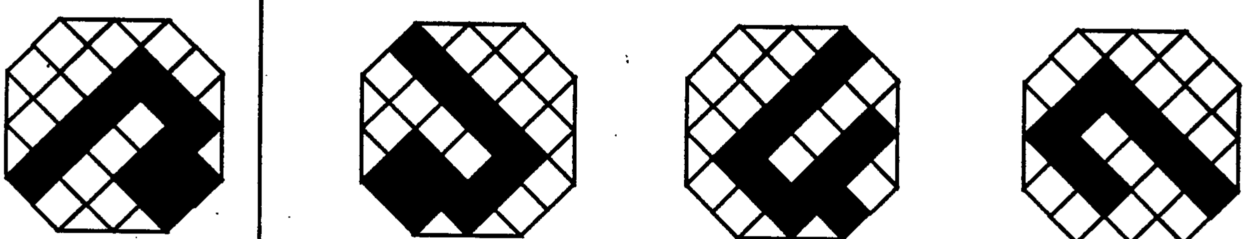

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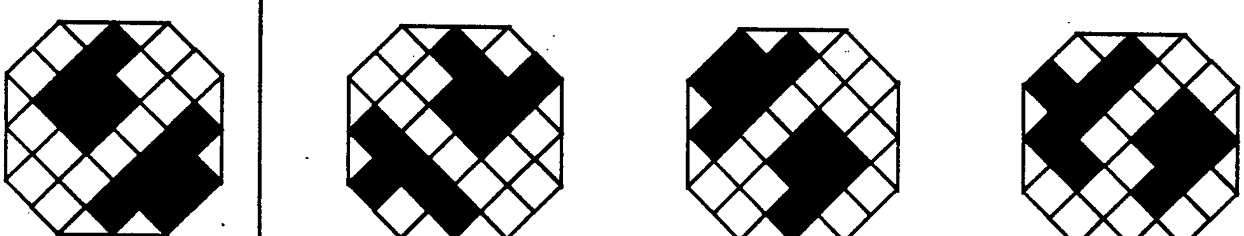

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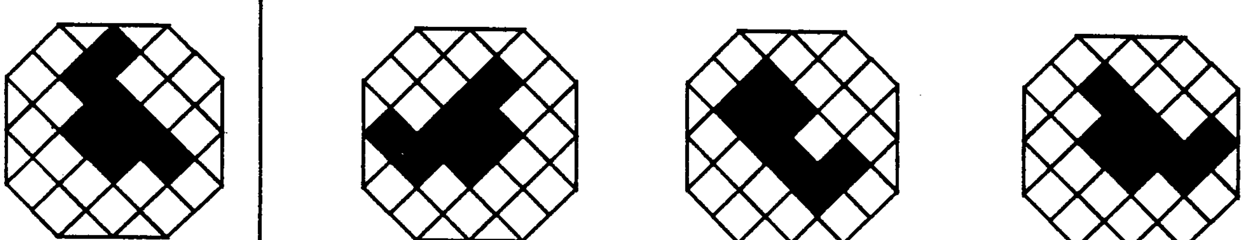

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APPENDIX D

NASA-TASK LOAD INDEX

7. SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD EVALUATION

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended on a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low and if they performed badly it must have been high. Yet others feel that effort or feelings of frustration are the most important factors in workload; and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to <u>your</u> experience of workload in the task(s) that you just performed. Each pair of scale titles will appear on a separate card.

<u>Circle the Scale Title that represents the more important contributor to workload for the specific task(s) you performed in this experiment.</u>

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern; we are only interested in your opinions.

If you have any questions, please ask them now. Otherwise, start whenever you are ready. Thank you for your participation.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*Perfect/Failure*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix B.

Sources-of-Workload Comparison Cards

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand

Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

16

Appendix C.

Subject ID: ______________ Task ID: ______________

RATING SHEET

MENTAL DEMAND

Low .... High

PHYSICAL DEMAND

Low .... High

TEMPORAL DEMAND

Low .... High

PERFORMANCE

Good .... Poor

EFFORT

Low .... High

FRUSTRATION

Low .... High

17

APPENDIX E

BEHAVIORAL ANCHORED RATING SCALES

Behavioral Anchored Rating Scales

Instructions: For each question below, place an "X"at one of the five levels of the scale that best describes your observations or experiences during the run that was just completed. A space is provided after each question for any comments you wish to add regarding your answer.

BASIC QUALITY 1 Land navigation ability

Issue 1-1 Equipment operation and information assimilation

a. Did the soldier have any difficulties in operating the navigation equipment?

5 — The soldier consistently displayed confidence in the operation of the navigation equipment, quickly and easily accessing and acting on the information the equipment provided.

4 —

3 — The soldier occasionally displayed some uncertainty in the operation of the navigation equipment, but generally did not have any major difficulties in using the equipment.

2 —

1 — The soldier often displayed uncertainty and frustration on the use of the navigation equipment, frequently repeating procedures to correct for errors in equipment operation.

Comment: ______________________________________

____

b. Did the navigation equipment enable the soldier to stay on azimuth and maintain the correct path?

5 — The soldier always stayed on azimuth and maintained the correct path deviating only slightly to avoid terrain hazards.

4 —

3 — The soldier occasionally deviated over 10 meters off the path but was able to find his way back.

2 —

1 — The soldier deviated off the path and became lost.

Comment: ______________________________________

____

Issue 1-2 Task conflict

a. Was the soldier able to use the navigation equipment while he was moving?

5 — The soldier maintained his pace without stopping while he was using the navigation equipment.

4 —

3 — The soldier stopped frequently to use the navigation equipment but for brief periods that did not significantly increase his time to navigate the path.

2 —

1 — The soldier always stopped to use his navigation equipment, often for long periods of time that led to a significant increase in his time to navigate the path.

Comment: ____

____

b. Did the navigatin equipment interfere with the soldier's ability to physically access and use other mission equipment (e.g. M16 rifle)?

5 — The soldier easily accessed, handled, and used all other items of equipment without interference by the navigation equipment.

4 —

3 — The soldier occasionally had to store or set down his navigation equipment in order to access and handle other mission equipment.

2 —

1 — The soldier was prevented from using other mission equipment in a timely manner due to the need to store or set down his navigation equipment.

Comment: ____

____

c. Did the navigation equipment distract the soldier when he was performing other tasks?

5 — The soldier consistently displayed an ability to focus on all tasks to completion without being distracted by his navigation equipment.

4 —

3 — The soldier was occasionally distracted by the navigation equipment causing minor delays in time to complete other tasks but no significant increase in errors.

2 —

1 — The soldier was frequently distracted by the navigation equipment causing major delays in time to complete other tasks and significant increases in errors.

Comment: ____

____

BASIC QUALITY 2 Hazard avoidance

Issue 2-1 Terrain hazard avoidance

a. Did the navigation equipment interfere with the soldier's ability to see ground hazards (e.g. fallen trees) and terrain contours (e.g. ditches)?

5 — The soldier always detected and successfully negotiated all ground-level hazards, maintaining good footing.

4 —

3 — The soldier did not detect some ground-level hazards and occasionally stumbled.

2 —

1 — The soldier did not detect most ground-level hazards and frequently lost his footing and fell.

Comment: ______________________________________

____

b. Did the navigation equipment interfere with the soldier's ability to see eye-level hazards (e.g. overhanging brush and tree branches)?

5 — The soldier quickly detected and successfully avoided contact with all eye-level hazards.

4 —

3 — The soldier did not detect some eye-level hazards in sufficient time to avoid contact.

2 —

1 — The soldier came into contact with all eye-level hazards along his path.

Comment: ______________________________________

____

Issue 2-2 Threat detection and recognition

a. Did the navigation equipment interfere with the soldier's ability to detect objects along the path?

5 — The soldier quickly detected all objects along the path.

4 —

3 — The soldier only detected objects that were on one side of the path on near his position.

2 —

1 — The soldier did not detect most objects along the path regardless of the location of the objects.

Comment: ______________________________________

____

b. Did the navigation equipment interfere with the soldier's ability to locate the enemy?

5 — The soldier immediately detected and accurately acquired the enemy.

4 —

3 — The soldier was often slow in detecting and locating the enemy.

2 —

1 — The soldier was often unaware of enemy contact.

Comment: ______________________________________

____

BASIC QUALITY 3 Combat readiness

Issue 3-1 Physical fatigue

a. Did the soldier maintain his momentum while navigating the path?

5 — The soldier maintained a consistent, rapid pace throughout all segments of the path.

4 —

3 — The soldier's pace was slow on some segments of the path?

2 —

1 — The soldier's pace was slow throughout all segments of the path and stopped frequently to rest.

Comment: ______________________________________

____

b. Was the soldier tired at the end of the path?

5 — The soldier was not perspiring or breathing heavier than normal; he was energized, and looking forward to his next run.

4 —

3 — The soldier was perspiring a little heavier than normal, and looking forward to a rest period.

2 —

1 — The soldier was perspiring heavily and had a difficult time catching his breath, needing immediate hydration and rest.

Comment: ______________________________________

____

Issue 3-2 Mental strain

a. Did the navigation equipment cause the soldier mental strain?

5 — The soldier had only good things to say about the navigation equipment and maintained a positive attitude throughout the path.

4 —

3 — The soldier occasionally commented on minor physical discomforts or difficulties caused by the navigation equipment, but did not suggest that these discomforts or difficulties interfered with his performance.

2 —

1 — The soldier was irritated, frequently commenting on physical discomforts or diffiulties caused by the navigation equipment and how they degraded his performance.

Comment: ____

b. Was the soldier interested in the navigation equipment?

5 — The soldier was enthusiatic throughout the path; often commenting that he would like to learn more about the equipment and the results of the study.

4 —

3 — The soldier did not speak much, maintaining a neutral attitude; he had a job to do.

2 —

1 — The soldier became discouraged with the equipment and just wanted to get the job over with.

Comment: ____

APPENDIX F

POST-TEST QUESTIONNAIRES

POST-TEST QUESTIONNAIRES

Subject No. _____

Post Test Questionnaire

(1) Please place a check (√) next to that equipment that you liked most.

Lensatic Compass and Paper Map with GPS [ ]

Helmet-Mounted Display (HMD) [ ]

(2) Please tell us what you LIKED and DISLIKED about this equipment in the space provided below.

Lensatic Compass and Paper Map with GPS ______________________

Liked ______________________________________

____

Disliked ______________________________________

____

Helmet-Mounted Display (HMD) ______________________

Liked ______________________________________

____

Disliked ______________________________________

____

Thank you!

Name: ______________________________ **Subject No.** _____

Please answer each of the following questions:

(1) Which eye do you normally use to aim your weapon?

Left ☐ Right ☐

(2) During the HMD study, over which eye did you place the display?

Left ☐ Right ☐

(3) Which display did you use to navigate in the HMD condition?

Map ☐

Rolling Compass ☐

Both ☐

If you checked "Both" to the previous question, what percentage of the time did you use each of these displays?

Map _____ %

Rolling Compass _____ %

= 100%

(4) During testing in the HMD condition, what percentage of time from the start to the end of the test path did you have the HMD down in front of your eye? _____ %

Thank you!

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13. ABSTRACT *(Maximum 200 words)*

The report describes a field study designed to measure soldier performance of land navigation and other mission tasks using current navigational equipment and to compare these data with performance using navigational information integrated on a helmet-mounted display (HMD). Measures of stress, cognitive performance, and workload were also obtained. The results indicated that the soldiers traveled less distance between waypoints and experienced lower levels of mental workload using information presented on the HMD than they did using current navigational equipment. As might be expected, differences in time between manual and automatic map updates were significant, but no differences were found between current equipment and the HMD condition in object detection, determination of magnetic azimuth, or call for fire tasks. Differences between conditions in levels of stress and cognitive performance were not significant.

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