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Detecting Targets From a Moving Vehicle With a Head-Mounted Display and Sound Localization

Christopher C. Smyth

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Christopher C. Smyth
Human Research & Engineering Directorate

Abstract

The effect of indirect vision systems on target detection and recognition is of interest to designers of future combat vehicles. In a field study, eight participants detected and identified "pop-up" targets on an outdoor experimental facility from a stationary and a moving vehicle while using a head-mounted display (HMD) and direct viewing as a control, with and without sound localization. A head-slaved camera mounted on top of the vehicle provided the image to the HMD. With sound localization provided by localized auditory cueing, the computer-controlled audio tones (intermittent at a 0.5-second interval) appeared to originate from the location of the target.

The results are that more targets were detected with direct viewing than with the HMD and from the stationary position than the moving vehicle. Although more targets were detected with direct viewing from the stationary vehicle without cueing, sound localization improved target detection in all other treatments. Similar comments apply to identification from the stationary position; however, fewer targets were identified from the moving vehicle with sound localization than without. The advantages of auditory cueing for target detection may have been limited by the choice of an intermittent tone for sound localization and the restricted search sector used in the experiment.

Ratings of task attention loading show that increased attention was needed for the detection task with sound localization, especially with the HMD. This is also true for the identification task. Workload test battery ratings show a significant increase in perceived workload with the HMD as compared to the direct vision. A test of situational awareness shows significant effects with decreasing trends in perceived stability and familiarity and an increased need to concentrate when one is using the HMD in the moving vehicle. Furthermore, most of the participants reported a general discomfort associated with motion sickness while in the moving vehicle with the HMD. There was no significant change in heart rate with test mode, suggesting that there was no impact of metabolic work on their performance. As a result of the study, the participants rated direct viewing as more useful than the HMD and the sound localization as being of more use with the HMD than with direct viewing.

ACKNOWLEDGMENTS

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The author further thanks Nancy Nicholas of ARL for technically editing this document.

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DETECTING TARGETS FROM A MOVING VEHICLE WITH A HEAD-MOUNTED DISPLAY AND SOUND LOCALIZATION

1. Introduction

In this section of the report, we describe the background rationale for the experiment, and we comment on the effects of camera and display selection on performance as well as the benefits of sound localization for target detection. We suggest criteria for optimal crew performance, including workload and situational awareness (SA), and we discuss the potential effects of motion sickness.

1.1 Background

The Army needs combat vehicles that are smaller, lighter, more lethal, survivable, and more mobile to support a rapidly deployable force. Combined with the need to assimilate and distribute more information to, from, and within the vehicle as the Army moves toward a digital battlefield, there is the need for an increase in vehicle and command, control, communications, computers, and intelligence systems integration and performance. Consequently, the Army will need sophisticated, highly integrated crew stations for these future combat vehicles. In support of this effort, the U.S. Army Tank Automotive Development and Engineering Center (TARDEC) is developing the TARDEC Crew Integration and Automation Test Bed (CAT) Advanced Technology Demonstrator (ATD). The purpose of the CAT ATD is to demonstrate crew interfaces, automation, and integration technologies required to operate and support future combat vehicles. The U.S. Army Research Laboratory (ARL) is providing human factors expertise in determining the effect of these new crew station technologies with a continuing series of studies and investigations. The results can dramatically increase the operational effectiveness and capabilities with fewer crew members, thereby contributing to smaller and lighter weapons systems. In this study, ARL conducted an experiment to determine the target detection and identification performance of vehicle crews who are using computerized indirect vision with head-mounted displays (HMDs) and optical systems.

1.2 Indirect Vision System

To satisfy the Army requirements for reduced gross weight and lower silhouette, as well as the need for increased crew protection against ballistic and directed energy threats, designers of future armored combat vehicles will place the crew stations deep within the hull of the vehicle. For protection against direct and indirect fire as well as chemical and biological agents, the crews will operate with their hatches closed and sealed. High intensity combat lasers that can penetrate direct vision blocks may force the crew to operate on the battlefield in a "buttoned up" mode, with indirect vision systems for driving and target search and engagement. The conventional optics consisting of periscopic vision blocks and optical sights will be replaced by electronic displays at each crew station and by externally mounted camera arrays on the vehicle. These vision systems will show computerized digital images that are electronically acquired by the camera arrays. The crew member will see a selected portion of the computerized display buffer that depends on his or her role and viewing direction. No doubt, by the incorporation of virtual reality display and camera components, future vision systems will appear to have a "see-through armor" capability with a seemingly direct view of the external scene through the armored hull of the vehicle.

1.3 Camera Selection

Before indirect vision systems can be considered for future vehicle designs, combat and materiel developers will need to know the potential impact on the crew's combat performance. During night operations, replacing the vision blocks with infrared thermal viewers improves the crew performance by enhancing visibility at low light levels. In daylight conditions, however, the use of indirect vision may cause a reduction in visual performance and SA. This is because of the decrease in visual resolution and field of view (FOV) of the current sensors and displays as compared to vision of the human eye through vision blocks. This reduction in visual performance may reduce overall combat performance. Further, the choice of camera configuration and placement on the vehicle can influence performance. For example, a single telescopic camera used in target search and detection may not have the performance of a multiple array of such cameras placed about the vehicle and electronically integrated to give a more naturally panoramic view. In the limit, the panoramic view would approach direct vision as the desired case.

1.4 Display Selection

The display selection will influence the vehicle design. The design may use a set of panel-mounted displays, either cathode ray tube (CRT) or flat panel liquid crystal displays (LCDs), which are fixed in a panoramic arrangement about the crew member's station. Another option is the use of a miniature HMD attached to the crew member's helmet. The display scene of the HMD can be "slaved" to head movements with a head tracker and for that reason, may appear more natural but with a limited FOV. Compared to the panel CRT and LCDs, the use of the HMD significantly reduces the size, weight, and power requirements for the crew station. However, the miniature displays that are currently available cannot match the brightness and resolution of the larger panel systems and may result in degraded crew performance. The display selection will also have an impact on the crew size needed to operate the armored vehicles of the future. We can expect in the future to have two- or three-person crews available. The form of computerized aiding used with the crew member's electronic associate[1] for the armored crew station is influenced by the display design. A panoramic design of

[1] crew member's associate program

panel displays for a two-person crew seated together may facilitate team interaction and performance. In contrast, the use of HMDs may tend to isolate the crew members and may require increased electronic communication between them.

1.5 Sound Localization

One problem of interest is the effectiveness of an HMD in target detection and identification with a head-controlled telescopic sight. A problem for target detection and identification with indirect vision systems is the inherently low visual acuity and limited FOV provided by the current display technology. On the modern digital battlefield, the crew may have advanced knowledge of the target's location. In this case, auditory directional cueing by sound localization should facilitate visual target detection by orienting the gunner toward the target. The choice of auditory cueing for a visual task reduces cognitive interference. This is shown by the literature about interference for performance of concurrent tasks with directed attention, time sharing, and workload (Wickens, 1992). Cueing can act as a secondary task, either supporting or interfering with the primary task, depending on the display format design. Wickens (1992) reports poor time sharing for two visual displays so spatially separated that both cannot be accessed by foveal vision simultaneously. However, displays of different modalities such as visual and auditory can have reduced interference with task performance.

1.6 Optimal Crew Performance

Another factor in the display design is the need to maintain SA and a mental model of the task. As noted by Endsley (1993), SA is a precursor to optimal performance, since a loss in awareness impacts decision making and leads to a risk of performance error. However, human operators can perform well with less-than-optimal display systems by increasing their efforts to meet the more demanding workload. The resulting increase in flow of information and tasks may result in a loss of SA; this is because the ability of humans to process information is innately limited. For this reason, besides demonstrating improved performance, a further criterion is that the display system should not generate excessive workload or decrease SA.

1.7 Motion Sickness

Another factor influencing crew performance is the possibility of motion sickness, which can occur in an enclosed cab area with spatial disorientation. As noted by Yardley (1992), motion sickness is provoked by sensory conflict between the visual and sensorimotor activities, which involve the vestibular system through head movements. Associated are a constellation of mainly autonomic symptoms such as pallor, drowsiness, salivation, sweating, nausea, and finally, vomiting in the more severe cases of motion sickness. Although some individuals may eventually adapt to situations that initially provoke sickness (Yardley, 1992), the occurrence may still be severe enough to arrest task performance until the symptoms subside.

2. Objective

The objective was to compare direct vision to an HMD, with and without audio localizing cues, for target detection and identification from a stationary and a moving vehicle. The results are compared to those for direct vision as representative of a perfect "see-through armor" vision system.

3. Methodology

The experimental apparatus, facility, and targets, questionnaires, participants, experimental design, experimental procedure, and participant's scenario are reported here.

3.1 Apparatus

The experimental apparatus is a Sony Electronics EVI-330 charge-coupled device color camera with video output to a Virtual i-O i_glasses HMD with stereo earphones. The apparatus is located in a high mobility, multipurpose, wheeled vehicle (HMMWV) with an on-board computer. The electronic camera is attached to a computer-controlled Directed Perception, Inc., pan-and-tilt mechanism that is mounted on the roof of the vehicle. Figure 1 shows a side view of the HMMWV with the electronic camera; a global positioning system antenna is to the rear of the camera. Figure 2 shows a close view of the camera on the pan-and-tilt mechanism.

Figure 3 shows a participant sitting in the front passenger seat and wearing a safety helmet with the HMD. A magnetic field sensor is attached to the top of helmet for head tracking. The participant wears stereo earphones under the helmet for sound localization by localized auditory cueing. He wears a Computer Instruments Corporation (CIC) UNIQ heart watch, which consists of a chest band and wrist exercise recorder for heart rate data. The earphones are acoustically driven by a computer-controlled Air Force three-dimensional (3-D) Sound Localization System with input from a tape recorder.

Figure 4 shows a view of the process control computer in the rear bay area of the vehicle next to the right rear passenger seat that is occupied by the experimenter during the experiment. A magnetic field source is mounted above and behind the front seat. An Ascension Technology Corporation "flock of birds" tracking processor provides the position and orientation of the field sensor to the computer, as measured in the magnetic field of the field source that is fixed to the frame of the vehicle.

Figure 1. HMMWV Experimental Vehicle With Roof-Mounted Camera.

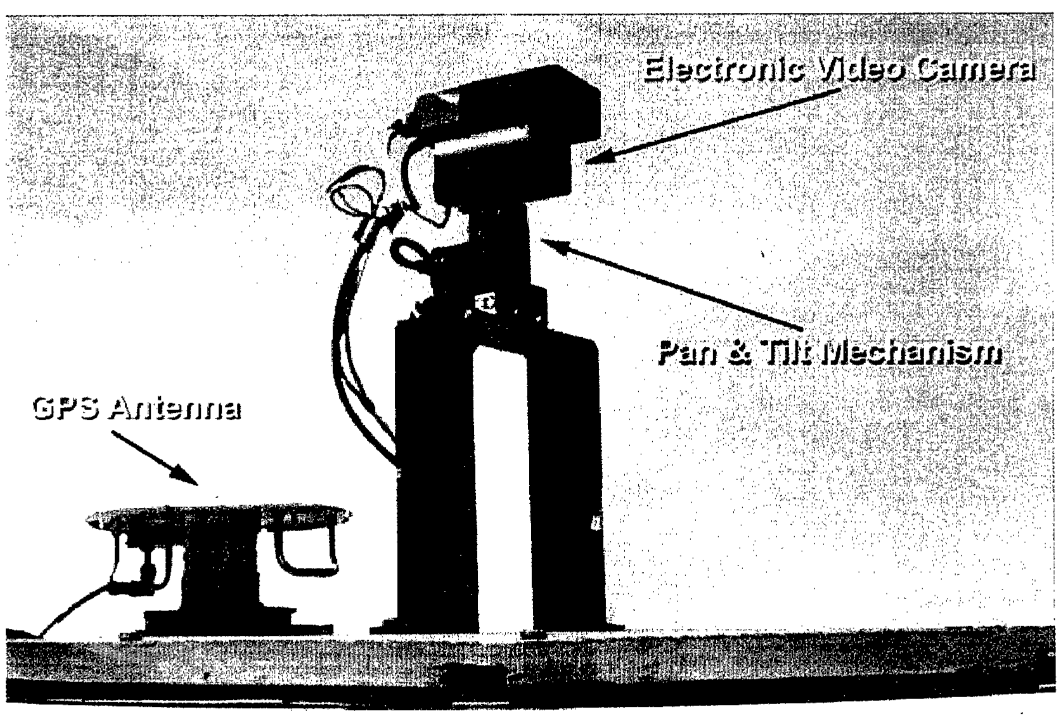

Figure 2. Close View of Camera With Pan-and-Tilt Mechanism.

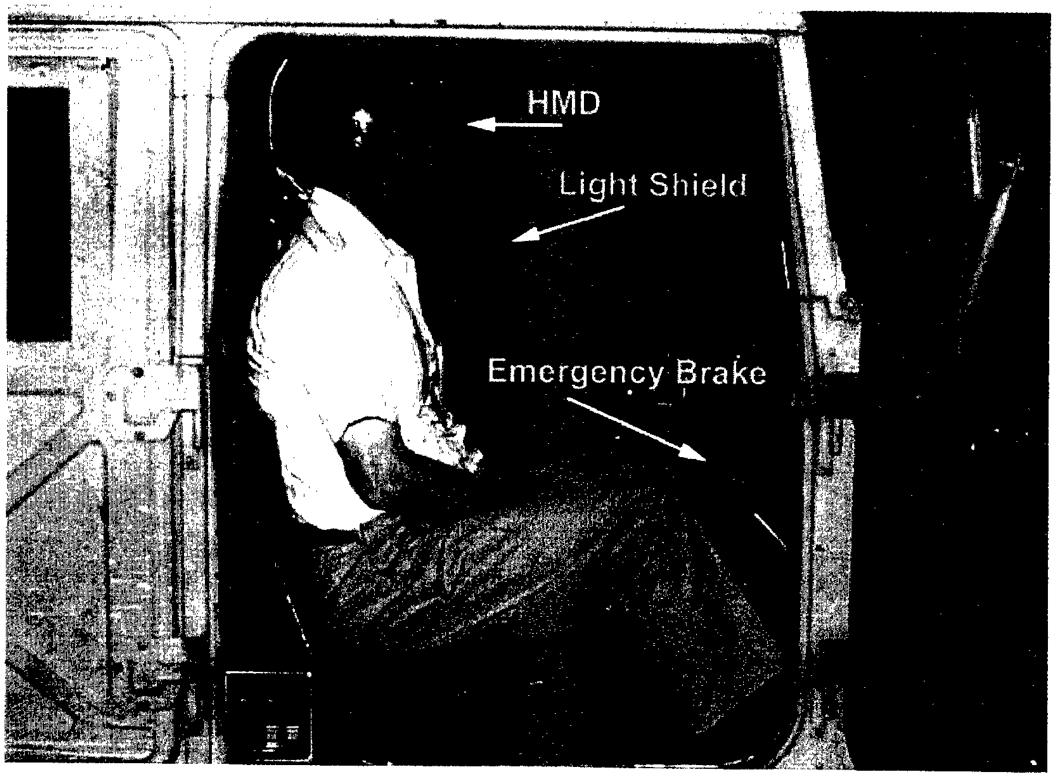

Figure 3. Participant With HMD.

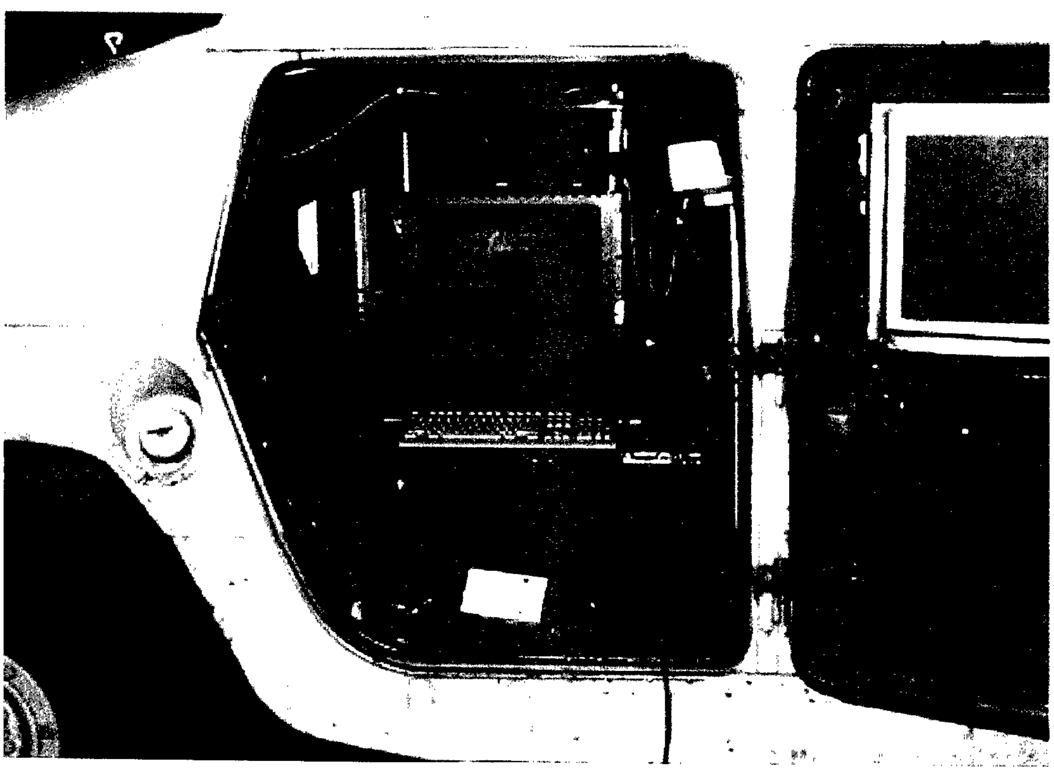

Figure 4. Experimenter's Computer Control Station.

The right front passenger's seating position was enclosed during the indirect vision portion of the study to keep sunlight from "washing out" the HMD. Opaque coverings were put over the right front windshield and the side window, and a wooden wall was placed between the driver and the passenger's area. A curtain was dropped behind the passenger's seat to complete the light shielding. During the direct vision studies, the passenger's area was open. The right side windshield and the right front door were removed from the vehicle to provide the participant with an unobstructed view to the right front and side.

3.1.1 Equipment Integration

Figure 5 is a schematic of the hardware used in the experiment. See Table 1 for a complete list of the equipment used in the study. As is shown in Figure 5, the NTS[2]-170 video output of the roof-mounted electronic camera is input to the HMD, and the participant sees what the camera "sees". Also fed by the camera output is a video monitor for the experimenter. The camera rotates with the participant's head through the computer-controlled pan-and-tilt mechanism with input from the head tracker. The tracking processor provides to the computer the position and orientation of the field sensor attached to the helmet, as measured by the magnetic field source fixed to the frame of the vehicle. The computer output commands the orientation and speed of movement of the pan-and-tilt mechanism for optimum linkage of the camera to the head direction. The participant controls the FOV of the camera with a manual zoom control that he or she holds in his or her lap. As well as controlling the camera, the FOV setting is output to the computer for reducing the tracking sensitivity at increased zoom and resetting it once zoom is removed. Finally, the computer provides the direction for the localized auditory cueing to the 3-D sound localization system. The mono-audio output of the tape recorder is modified by the 3-D sound localization system to provide audio signals shifted in phase and intensity to the stereo earphones provided for the participant and the experimenter. The latter uses his earphones to ensure proper functionality of the audio system during the sound cueing portion of the experiment.

3.1.2 Indirect Vision System

The visual characteristics of the indirect vision system are listed in Table 2, along with those of direct vision for comparison. The table shows that the indirect vision system is limited by the resolution and FOV of the HMD used in this study. At 30 degrees, the horizontal FOV of the HMD is 61% of the 48.8-degree FOV of the camera. Because of the differences in FOV of the camera and HMD, the scene on the HMD appears expanded 1.63 times that of the real world, making the targets 0.61 times smaller in linear size. Furthermore, the HMD with 180,000 (528 x 340) rasters has 68.8% of the angular resolution of the camera 768 x 494 rasters. For these reasons, targets on the HMD appear 0.42 smaller in linear size than they would with an HMD optically matched to the camera. The electronic camera is auto-focusing with automatic white balance and brightness

[2] National Television Standards

control by auto-iris. The zoom for magnification is manually controlled and desensitizes the head response to allow directional control by the participant at the higher magnification.

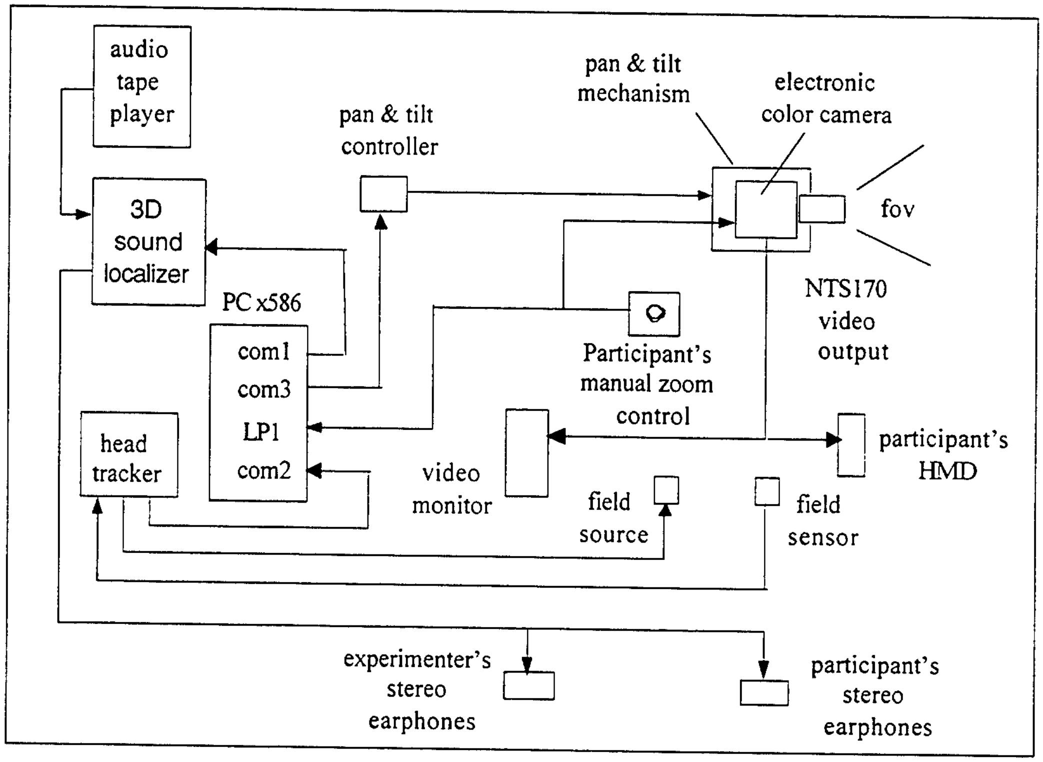

Figure 5. Schematic of Equipment Layout.

Table 1. Experimental Apparatus

1. High mobility, multipurpose, wheeled vehicle.
2. Sony Electronics' EVI-330 color camera.
3. Directed Perception's pan-and-tilt, computer-controlled, stepper motor mechanism.
4. Ascension's Flock of Birds (magnetic field) head tracker.
5. Virtual i-O's i-glasses, liquid crystal, video game, HMDs.
6. Safety helmet with field sensor attached.
7. Manual control mechanism for color camera telescopic zoom.
8. Industrialized personal computer, x586.
9. Tape recorder with pre-recorded electronic sound source.
10. Air Force 3-D Sound Localization System.
11. Stereophonic ear-plug phones.
12. Video monitor.
13. CIC's UNIQ heart watch (model 8799) exercise recorder.
14. Light shielding for the windshield, side window, and passenger's area.
15. Two-way hand radio.
16. Hand paddle for signaling.
17. Hand-held binoculars (7X).

Table 2. Vision System Properties

Property	Indirect Camera	Indirect HMD	Direct Binoculars	Direct Natural
rasters (HxV)	768x494	528x340	infinite	infinite
FOV (degs)@1x	48.8	30	76.3	170
Magnification	12x	1x	7x	1x
FOV @ mag	4.1	30	10.9	170

3.1.3 Sound Localization System

The acoustic properties of the auditory source used in the sound localization portion of the experiment are listed in Table 3. The input sound from the tape recorder to the sound localization system is a sequence of 100-millisecond chirps (i.e., sweep sinusoids) presented at 0.5-second time intervals. The localization is synthetically generated (Wenzel, 1991) as localized auditory cues from the Air Force 3-D sound localization system by convoluting the input sound with a directional sensitive head-related transfer function (HRTF) measured for a manikin standard. The system produces different stereophonic sounds for each ear through the earphones. The sound cue appears as a stereophonic sound coming from the target along the bearing to the participant. He or she hears a chirping sound coming roughly from the direction of the target and tends to turn his or her head toward the sound.

Table 3. Sound Source Properties

Property	Value
Characteristic	linear sweep sinusoid
Spectrum range	500 to 4500 Hertz
Duration	100 milliseconds
Delivery rate	2 Hertz

It is interesting to note that the literature (Begault & Wenzel, 1990) about synthetic sounds generated in earphones reports that humans have a roughly 20-degree localization accuracy in both azimuth and elevation. The localization is reported to be more accurate at a 30- to 60-degree angle to the side of the head than at other angles. The sound source tends to be localized in a bow-tie shape as the source is moved in the horizontal plane about the head, with the source becoming internalized for source bearings within 30 degrees of the lateral plane through the cranial midline, approached from either the front or back.

Furthermore, the source tends to appear elevated for sources to the front and depressed below the horizontal plane for sources to the rear. Experiments have shown that the best localization occurs for sources placed at 60 and 150 degrees for the right ear and 210 and 300 degrees for the left ear where the bearing is measured in the horizontal plane from the person's nose about the head right to left. It is believed that the internalization of a sound source which is presented to the front is the result of visual dominance; however, this may be attributable to earphone design (Gierlich, 1992; Moller, 1992). Reversals of apparent direction between front and rear are common (about 11%) for sources near the cranial midline (Wightman & Kistler, 1989). This may be because frontal sources not seen are interpreted as being to the rear.

3.1.4 Vehicle Computer

The computer program controlling the equipment integration was executed by the experimenter at the start of each block of experimental runs. The program first reads data files and then hibernates. The data files selected by the experimenter for the block specify the target set and order of presentation, the locations of the targets on the experimental facility, the vehicle mode (stationary versus moving), the starting location, and if moving, the vehicle speed and direction of travel. The experimenter releases the program from hibernation with a key push from the keyboard at the start of an experimental run and returns it at the end with another key push. The run number and the designator and location for the corresponding target are displayed on the computer monitor at the start of the run to verify the functionality.

During the sound localization trials, the auditory cueing from the sound localization system is turned on by the computer during the trial run and is otherwise suppressed in response to the keyboard entries. The direction for sound localization is computed from the target location on the experimental facility, the position of the vehicle, and the head orientation of the participant within the vehicle. The target location is determined from the trial run and the files on the target presentation order and the locations of the targets on the facility. For the moving studies, the computer estimates the position of the vehicle from the starting position, the time lapsed since starting the trial, and the speed of travel along the trial route. The head orientation is read in real time from the head tracker.

3.2 Target Facility

The participants were evaluated on an outdoor, computer-controlled, small arms firing facility, which is 600 meters long. The facility, known as the small arms shooting performance research facility (SASPRF), is located at Aberdeen Proving Ground (APG), Maryland, and is used for measuring the weapon performance of soldiers. The facility is permanent and consists of 160 stationary "pop-up" targets arranged in four lanes of 40 targets each, spaced at distances from 10 meters to 550 meters from the firing line. Figure 6 shows an aerial view of the firing facility with all targets in a raised position. The figure shows a control center at the firing line and an access road paralleling the left side of the facility. The targets are operated by a computer system in the control center. Figure 7 shows a view of the control center. The computer system can present programmed arrays of targets at any distance, time interval, and sequence. The system records and reduces events, such as targets presented, target time, target hits, and times of hits.

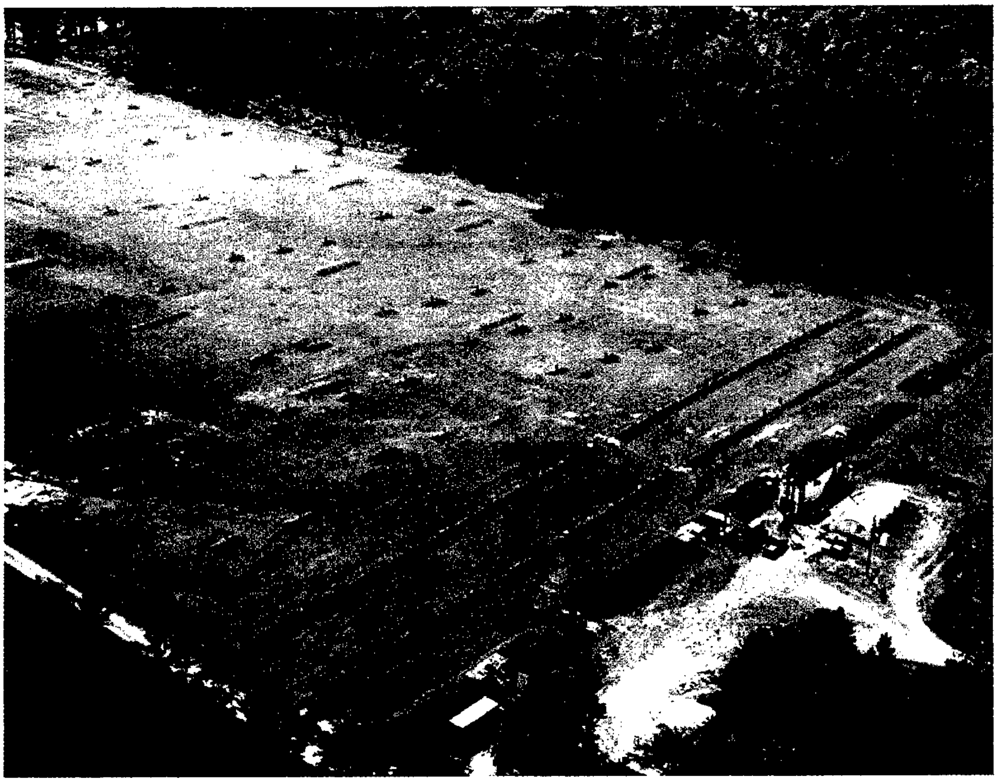

Figure 6. Aerial View of the Target Facility.

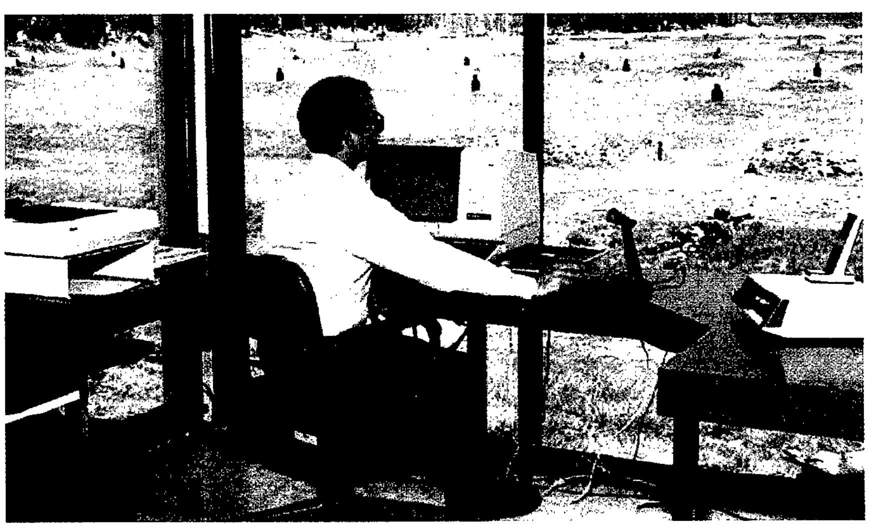

Figure 7. View of Target Facility Control Center.

3.3 Targets

The pop-up targets consist of an E-type silhouette mounted on a pneumatic target mechanism that is capable of raising and lowering the silhouette under control of the facility's computer. Figure 8 shows a sketch with dimensions of a target board. The target is a "full trunk" (18.5 in. wide by 29 in. high) human silhouette with an 8.5- by 10-inch head. The targets used in this study are colored olive drab. The targets stand roughly 24 inches above the grass line at the shoulder. All targets used in this study have a dull black Landolt C ring (8.66-in. outer diameter, 1.625-in. thickness) painted on the face for identification, with the 1.625-inch ring gap oriented up, down, left, or right, in accordance with a random assignment. The rings were visible against the targets with the binoculars and telescopic zooming but not with direct vision.

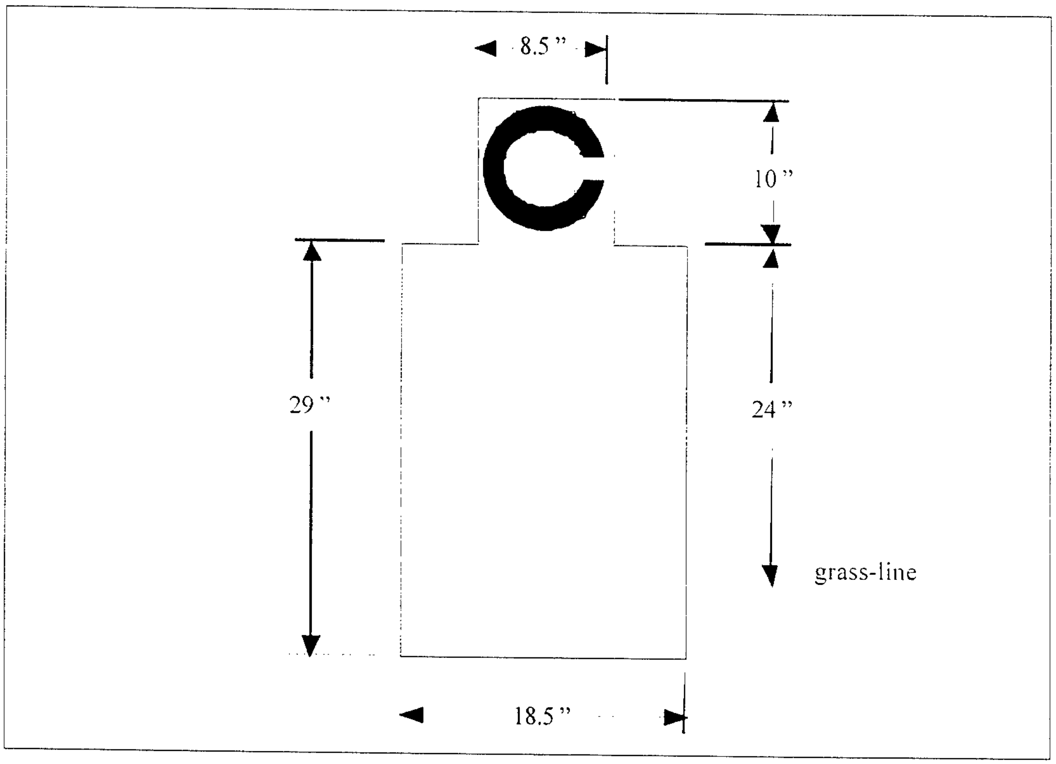

Figure 8. Target Silhouette.

3.4 Participants

Eight Department of Defense civilian and military male volunteers who have good eyesight (nominal 20/20, normal or corrected by glasses or contacts) served as participants in this study. Three of the subjects were enlisted military assigned to the Aberdeen Test Center, APG. Three subjects were military and two were civilian volunteers assigned to ARL. The demographics of the participants are listed in Table 4 in order of rank, along with the visual acuity (far vision) and hearing acuity as determined from medical records and measurements with a Titmus visual acuity meter.

Table 4. Demographics of Participants

Rank	Age	MOS	Education	Far Vision Acuity	Far Vision Corrected	Hearing Left	Hearing Right	Experience Military	Experience Computers
SPC	20	11M	GED	20/18	none	low	low	Bradley driver	PC/video games
SPC	28	11M	HS	20/22	none	tinnitus	low		
SGT	24	11M20	HS	20/20	contacts	good	good	TOW operator	PC/video games
SFC	36	54B4H	BS	20/20	glasses	good	good	artillery	PC
MAJ	36	ORD	MS	20/30	none	good	good	com	PC/video games
MAJ	40	51A	MA	20/20	glasses	good	good	mech units	PC/video games
GS14	61	HFE	BS	20/30	glasses	good	good		PC
GM14	47	HFE	MS	20/20	none	good	good		PC/video games

TOW = tube-launched, optically tracked, wire-guided (missile)

3.5 Experimental Design

3.5.1 Design

The experimental design was a fixed factorial 2x2x2 experiment with repeated measures on the vehicle speed, vision mode, and cueing factor, and the participants as a random factor.

The independent variables are

1. two levels of road speed (stationary versus 10 mph),
2. two levels of vision (direct versus HMD), and
3. two levels of cueing (none versus sound localization).

The dependent variables are

1. the times to complete detection,
2. the target detection events scored as a success or failure,
3. the times for identification, given detection,
4. the target identification scores,
5. the correct identification scores,
6. the number of false target detections,
7. the heart rate, and
8. the scores from a battery of questionnaires.

3.5.2 Null Hypothesis

There are no differences in target detection and identification, false alarm rate, heart rate, or questionnaire scores among the fixed factorials.

3.6 Questionnaires

A battery of questionnaires was used to measure the subjective effects of the treatments on different aspects of the task workload and consists of the following items:

3.6.1 Attention Allocation Loading

A questionnaire was used for rating the allocation of attention to the visual, auditory, cognitive, and motor processing channels of the human operator according to loading factors (McCracken & Aldrich, 1984). These loading factors are used in task analysis workload (TAWL) simulations (Allender, Salvi, & Promisel, 1998). The questionnaire (see Appendix A) consists of a set of four 7-point, bipolar scales for rating the attention loading on each channel, with verbal anchors for corresponding activities overlaid on the scales.

3.6.2 NASA-TLX Workload

The National Aeronautics and Space Administration (NASA)-Task Loading Index (TLX) workload questionnaire (Hart & Staveland, 1988) was used for rating the perceived workload in terms of task demand and interaction. The NASA-TLX is a multidimensional rating procedure for the subjective assessment of workload. Workload has been defined as a hypothetical construct, which represents the cost incurred by the human operator to achieve a specific performance level. The construct is composed of behavioral, performance, physiological, and subjective components, which result from the interaction between a specific individual and the demands imposed by a particular task. The questionnaire (see Appendix A) consists of six scales that relate to the demands imposed on a subject and the interaction of the subject with the task. The Mental, Physical, and Temporal scales measure the demands, while the Effort, Frustration, and Performance scales relate to the interaction with the task.

3.6.3 Motion Sickness

A motion sickness questionnaire used for the subjective estimation of motion sickness (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989). The questionnaire (see Appendix A) consists of 4-point, bipolar rating scales consisting of verbal descriptors for the level of sickness of 16 symptoms such as general discomfort, eye strain, dizziness, and nausea, among others. Based on data from a factor analysis of simulator sickness experiences, a procedure has been developed (Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992) for reducing the scores to subscales for the symptomatic components of oculomotor stress (eye strain), nausea, and disorientation, and a measure of total severity.

3.6.4 SART Situation Awareness

The Situation Awareness Rating Technique (SART) questionnaire used for rating SA (Taylor, 1988, 1989; Taylor & Selcon, 1994). The SART questionnaire (Selcon, Taylor & Koritsas, 1991) was designed to measure subjective ratings of non-attention factors such as domain knowledge or schemata and experience, the cognitive nature of the information received while the task is being performed, and the workload needed to process the information. The questionnaire (see Appendix A) uses ten independent seven-point bipolar dimensions, which are, in turn, classified into three major domains of situation demand, supply, and understanding. The ten dimensions of the questionnaire are instability, variability, and complexity of the situation for the demand domain; the arousal, spare mental capacity, concentration, and division of attention for the supply domain; and the quantity, quality, and familiarity of the information for the understanding domain. The questionnaire is the result of a study by Taylor (1988, 1989) involving subjective ratings of bipolar awareness constructs elicited from air crews about their experience and knowledge, using a repertory grid technique. Taylor reportedly found that ten independent bipolar constructs emerged from the 44 constructs provided by the air crew, as determined by eliciting frequency, principal component loading, and inter-correlation clustering. These were reduced by Taylor to the ten dimensions of the SART questionnaire.

3.6.5 Exit Evaluation

In addition, a utility rating questionnaire was applied at the end of the experiment. A sample questionnaire is shown in Appendix A.

3.7 Control of the Experiment-wise Type I Error

A problem in analyzing the data from this experiment is the control of the experiment-wise Type I (false positive) error. This is because the chance that a measure will erroneously prove to be significant increases statistically with the number of analyses performed. In all, 105 measures were collected for each trial run. These include 12 target detection and identification events, with each event consisting of a detection score, a detection time, an identification score, an identification time, and a correct identification score. In addition, four false alarm scores, a heart rate, six workload questions, 10 SART questions, 16 motion sickness questions, and two sets of four attention allocation ratings were collected. The strategy for controlling the error is based on a judicious selection of the measures for analysis. Further, careful consideration is given to the statistics involved since inflated Type I error can result in an analysis without corrections for departures from normality in the within-subjects effects. Note that lack of sphericity is not a problem for the main factors in this analysis since only two treatments are used for each factor. The Holm simultaneous testing procedure (Neter, Kutner, Nachtsheim, & Wasserman, 1996) is used to partition the overall alpha level of .05 among the family of planned separate analyses. The Holm procedure is a more powerful form of the Bonferroni procedure, which is used to control family-wise Type I error. The approach is now described in greater detail.

The overall task performance of target detection and identification is determined with a canonical correlation analysis (Pedhazur, 1982), which was applied to the detection and identification times and event measures. The analysis computes linear combinations for the dependent and independent variables so that the maximum possible correlation is obtained between two sets of canonical variates. The canonical correlation analysis is an overall statistical test and does not indicate the separate contributions of the multiple dependent variables to the differences between the factorial groupings. As an additional control of the Type I errors following overall significance, separate univariate analyses are applied to the dependent measures via a repeated measure (RM) analysis of variance (ANOVA). In a parametric analysis, the distributions for the dependent measure must satisfy normality and homogeneity of variances without correlation of the variances with the means. To maintain the error rate for all pair-wise comparisons, the contrast of *post hoc* comparisons between treatment means are computed with Tukey's Honestly Significant Difference Test from the mean differences and the ANOVA error residual (Keppel, 1982). Here, sphericity for the within-subjects effects is not required for the main factors since there are two treatments for each factor. In those cases in which the distributions for the dependent measure are not normal, a nonparametric (NP) Friedman ANOVA by ranks is used for univariate analysis, followed by a conservative Scheffé pair-wise comparison test for the contrast of rank means.

Several techniques are used to reduce the data for analysis from the questionnaires. Different researchers have developed these questionnaires, and we treat the results in separate analyses. First, factor analysis (Cooley & Lohnes, 1971) is used to reduce the measures to factorial components for statistical analysis. The number of factorial components used in the analysis equals the number of groupings that are recognized in the literature as being appropriate for the questionnaire. For those cases in which no such standard exits, only two factorial components are used. A univariate statistical analysis is applied to each factorial component in turn, starting with the first factorial since this component contains the largest portion of the variance until significance is attained. The components are analyzed by parametric methods unless the components are non-normal distributions, in which case, a nonparametric method of analysis is applied to the first component. In this way, the fewest possible analyses are applied to each factorial decomposition. Following significance of the factorial component, the data for the measures are analyzed according to standard practice for the questionnaire.

It is standard practice to reduce the data for the perceived performance questionnaires (workload, SA, and motion sickness) to single measures by a weighted summing of the component scales. For example, the NASA-TLX workload questionnaire (Hart & Staveland, 1988) consists of six bi-polar scales with semantic anchors, three scales for task demand, and three for task interaction. A single grand measure of workload may be calculated by summing the ratings of the component scales (Hendy, Hamilton, & Landry, 1993). Also of interest are the separate sums for the task demands and interaction scales. In contrast, the SART questionnaire consists of ten bi-polar scales, three scales for situational demands, four for supply, and three for situational understanding. A single overall measure of SA is calculated from the sum of the ratings for the supply and understanding, minus the sum of the ratings for the demand scales (Selcon, Taylor & Koritsas, 1991; Taylor, 1988, 1989). Of further interest are the separate sums for the demand, supply, and understanding ratings. Finally, the motion sickness questionnaire (Kennedy et al., 1989) consists of 16 multiple choices. In data reduction, these are mapped to numerical scales that are grouped into ratings for a nausea symptom, a disorientation symptom, and an oculomotor symptom (Kennedy et al., 1992). A single measure of total severity is calculated from the weighted sum of these ratings.

Once the planned analyses are completed, the overall family-wise alpha level of .05 is partitioned among the statistical tests with the Holm simultaneous testing procedure (Neter, Kutner, Nachtsheim, & Wasserman, 1996) to control the Type I error. With this procedure, the alpha level is partitioned among the family of tests, according to the ranking of the (two-sided) probabilities of significance. With each acceptance of the alternate hypothesis, the family-wise alpha level is adjusted for the tests remaining. This process is continued until a test is reached for which the null hypothesis applies; the null hypothesis is then accepted for this and all remaining trials.

3.8 Procedures

The experiment was conducted in May 1998, with the trials limited to the hours between 1000 and 1400 to provide relatively consistent sky lighting. In this experiment, the participants searched for a target across the right side visual front from either a stationary or a moving HMMWV. The stationary vehicle was parked to the left side of the course at an observation point on the 100-meter course line. The moving vehicle was driven at a constant 10 miles per hour along the access road on the left side of the course from the 25-meter line toward the 550-meter end. The participants started looking for a target when the moving vehicle reached the 50-meter line and ended their search at the 150-meter line; in this way, the participants saw practically the same target configurations in both vehicle modes. For safety reasons, vehicle movement was restricted to the access road on the left side of the firing facility.

The targets were raised for display and lowered one at a time under computer control by the SASPRF personnel supporting the experiment. In this experiment, 34 targets are used for training and investigation. Table 5 lists the targets with location and Landolt ring gap orientation. The targets are plotted in Figure 9. They are positioned about the 150-meter line, 200-meter line, 250-meter line, and 300-meter line of the course. These targets extend 50 meters to 225 meters across a 60-degree sector to the right side from the 100-meter line observation point. All but the six far right targets are seen against a light green field grass background; the remaining six are set against a dark brown tree line background. All targets face up range except for the three right most targets which were turned 30 degrees to the right of centerline. The target design follows from a preliminary study which showed that for statistical variations in sightings to occur, the targets need to extend from 50 meters to 125 meters for the indirect vision with the HMD and 200 meters for direct vision (see Appendices B and C).

Table 5. Target Location (meters) and Landolt Ring Gap Orientation

Target	x	y	Orientation	target	x	y	Orientation	target	x	y	Orientation
A20	96	155	R	B20	40	155	D	C20	-13	155	U[ab]
A21	81	150	D	B21	27	150	L	C23	-13	205	L
A22	68	145	R	B22	13	145	L	C24	-27	200	D
A23	96	205	U	B23	40	205	R	C25	-41	195	L[a]
A24	81	200	D	B24	27	200	U	C26	-13	255	R
A25	68	195	L	B25	13	195	D	C27	-27	250	U
A26	96	255	R	B26	40	255	R	C28	-41	245	D[a]
A27	81	250	U	B27	27	250	U	D23	-69	205	L[a]
A28	68	245	R	B28	13	245	L	D24	-82	200	D[ab]
A29	96	305	L	B29	40	305	D	D25	-96	195	U[ab]
A30	81	300	R	B30	27	300	U				
A31	68	295	R	B31	13	295	D				

[a]tree line background
[b]angular offset
Note: Coordinate system origin at center of firing line with positive y-axis down range and positive x-axis to left of centerline.
Gap orientation Key: L-left, R-right, U-up, D-down

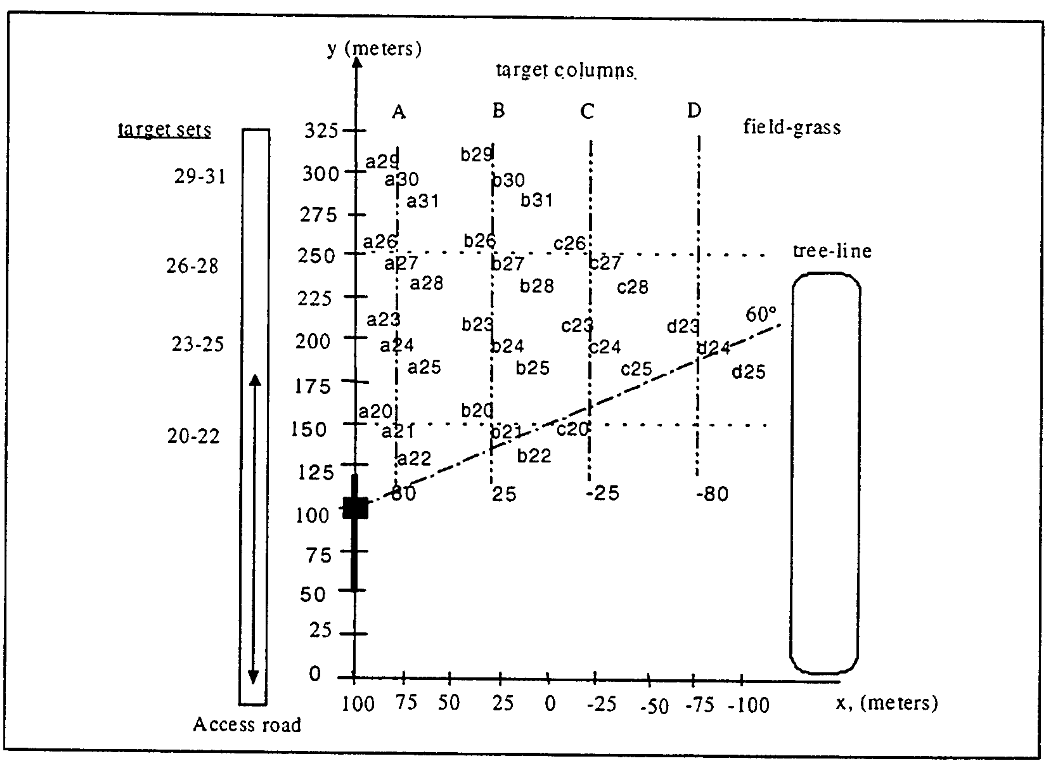

Figure 9. Target Deployment.

Eight sets of target sequences were used in the experiment. The sequences were drawn from target groups formed by subdividing the SASPRF into three equal 50-meter bands and the sector into three equal 20-degree zones. Eight sets of 17 targets with 5 for training and 12 for evaluation were selected so that all bands and sector zones were equally represented as closely as possible. The presentation order of the targets within each set was randomly selected so that all ranges and bearings appeared equally likely. See Table 6 for the order of target presentations. All participants saw the target sequence sets in the same order because of the limited number of targets available and to facilitate control.

Table 6. Target Presentation Order

		Target Sets							
Trial Phase	Order	1	2	3	4	5	6	7	8
Training	1.	B22	A28	C23	B26	A26	B28	B25	A25
	2.	B26	B23	A20	B20	B22	A23	B20	C23
	3.	A23	A20	A28	A22	A21	B20	A22	B22
	4.	A27	C23	B20	A26	B23	C25	A28	B26
	5.	A22	B20	B25	B24	C25	A20	C23	B25
Evaluation	6.	C23	B22	B30	C27	B26	B29	A20	B23
	7.	Nnn	B25	A21	Nnn	B20	Nnn	C27	Nnn
	8.	B20	C28	C25	A28	D25	A26	A27	D24
	9.	C26	C20	B24	C20	Nnn	Nnn	B26	A29
	10.	A20	Nnn	B26	Nnn	A31	B21	A25	B20
	11.	Nnn	A29	A23	C25	C26	B25	C24	Nnn
	12.	A25	C24	Nnn	Nnn	C24	Nnn	D25	B28
	13.	D24	A27	C27	A29	Nnn	C23	Nnn	A23
	14.	A30	A24	Nnn	Nnn	A20	A24	B31	Nnn
	15.	B28	Nnn	B21	D24	B31	Nnn	Nnn	A21
	16.	B23	D25	Nnn	B23	A27	B27	C20	Nnn
	17.	A28	Nnn	A31	B28	Nnn	D23	Nnn	C26
	18.	Nnn	A22	Nnn	B22	C20	C28	B22	C20
	19.	C20	Nnn	A26	A21	Nnn	A22	A31	A28
	20.	Nnn	B27	C20	B30	A23	A30	Nnn	B30
	21.	B29	B31	D23	A25	B24	C20	B24	C25

Nnn = no target presented.

The participants were evaluated in a counterbalanced manner according to the schedule of Table 7, which shows that the trial runs were grouped in blocks by the vehicle motion, the vision mode, and the cueing format for experimental convenience. That is, the participant was evaluated first on all runs for the vehicle in motion, followed by those runs for the parked vehicle or in the reverse order. Further, the participants were evaluated in a counterbalanced manner with the direct or indirect vision mode for each vehicle motion block. For each vision mode, they received a block of experimental runs without localizing cues and a block with audio cueing. For each such block combination, the participant was first trained in that mode with the first five targets of the scheduled target set sequence. He was then evaluated on a sequence of 16 presentations consisting of the remaining 12 targets from that sequence set and 4 additional no-target presentations randomly interspersed as a check on the false alarm response.

Table 7. Participants' Assignment

Vehicle	Stationary				Moving			
Mode	Direct		HMD		Direct		HMD	
Cueing	None	3Dsd	None	3Dsd	None	3Dsd	None	3Dsd
S1	1	2	3	4	5	6	7	8
S2	5	6	7	8	1	2	3	4
S3	3	4	1	2	7	8	5	6
S4	7	8	5	6	3	4	1	2
S5	2	1	4	3	6	5	8	7
S6	6	5	8	7	2	1	4	3
S7	4	3	2	1	8	7	6	5
S8	8	7	6	5	4	3	2	1

3Dsd = three-dimensional sound

3.9 Participant's Scenario

Following the participant's arrival at the facility, the experiment was described to him. A volunteer agreement affidavit (see Appendix A) was given to him to read, and informed consent was explained.

The participant received an orientation and safety briefing after he agreed to take part in the experiment and signed the volunteer agreement. The visual acuity (far) and self-reported hearing acuity (left and right ears) data were collected from the participant, along with demographic data. The procedure, the participant's role as an experimental subject, and the purpose and nature of the questionnaires were explained to him. After these preliminaries, the participant was assigned a sequence of vehicle motion, vision mode, and cueing format blocking combinations, in accordance with the schedule.

Before the study was started, the participant viewed all targets in the upright position from the 100-meter observation point. All participants were knowledgeable of the facility since they had fired small arms for qualification at previous times. They quickly learned which targets were used in the study, and by their viewing the targets, this learning effect was removed from the data. Otherwise, the learning effect would have increased the statistical variance and thus reduced the significance.

The participant was trained and evaluated on the target sequence set for each block combination as determined by the schedule. Before the experimental sequence, the HMD was put on the safety helmet or removed as needed for the block combination. The light shielding was put in place about the passenger's area or removed with the right windshield and forward door, accordingly. The participant placed the earphones and donned the safety helmet. For those sessions that involved audio localization, the participant set the sound amplitude and checked the sound localization with a demonstration computer program before experimentation began. The experimenter set the data files for the on-board computer and activated the process control program. During the initial training for those sessions with sound localization, the experimenter checked with the participant to ensure that the stereophonic sound cueing appeared to originate from the targets.

At the start of a run, all targets were down, and the participant turned toward the facility front with his eyes closed and his head down. In the indirect vision mode, the participant aligned the scene in the HMD with the marker and closed his eyes while the experimenter viewed the camera return on a separate video monitor. The experimenter alerted facility control to activate the target by quickly raising a white paddle. A second later, the experimenter told the participant to commence searching for the raised target. In the sound localization mode, the experimenter activated the sound cues as well. The 1-second delay allowed the controller to respond and the target mechanism to activate. The participant informed the experimenter by voice when he had spotted the target and the experimenter confirmed the sighting to the facility controller by again raising his white paddle. Using the electronic telescope at full magnification in indirect vision or a set of hand-held binoculars in direct vision, the participant then zoomed in on the target and informed the experimenter of the Landolt ring's orientation. Again, the experimenter quickly raised his paddle and told the controller of the reported orientation with a hand radio set. The experimenter was seated behind the participant and the paddle was beyond his field of vision. The participant was allowed no more than 25 seconds to complete the trial, 15 seconds to detect, and 10 seconds after detection to identify the target. The facility control officer pressed a computer keypad button when the paddle was raised for detection and identification and entered the reported orientation. The facility control computer recorded the target designator, the time that it was raised, and the times that the button was pushed for detection and identification, along with the orientation. The experimenter was in radio contact with the facility control personnel at all times through a hand radio set. Facility control told the experimenter when the trial time elapsed if a detection or identification was not made. In the sound localization mode, the experimenter turned off the sound cues at the end of the run.

During a run with direct vision, the participant sat in the passenger's seat of the vehicle and wore the safety helmet with earphones. The right windshield and the front right door had been removed to allow an unobstructed view to the right front and side. The participant searched with natural unaided vision for the target and then used a set of hand-held binoculars to see the Landolt ring's orientation. In indirect vision, the participant sat in the front passenger's seat and wore the safety helmet with the HMD and earphones. The front passenger's area had been completely enclosed with light shielding. The participant saw the target through the HMD with a video link to the head-coupled electronic camera on top of the vehicle. As the participant turned his head, the camera turned with him. The participant searched with the camera at full FOV for the target and then used the telescopic zoom to see the Landolt ring's orientation. He manually controlled the FOV of the camera with a zoom control that he held in his lap during the experiment. In sound localization, the participant heard a computer-controlled beeping sound in his ears, apparently coming from the direction of the target. While in the stationary vehicle, the participant searched from the 100-meter line. In the moving vehicle, he started his search as the vehicle passed the 50-meter line and ended at the 150-meter line. At 10 mph, the vehicle reached the 117-meter line in about 15 seconds and the 150-meter line 10 seconds later. Of course, the vehicle was moving toward the target, and the actual detection and identification distances were a function of the search times. At the end of the run, the vehicle was stopped and backed to the start of the course at the 25-meter mark in preparation for the next run.

At the end of each target set sequence, the participant's heart rate was recorded. Heart rate has been reported to be an indicator of workload, and the participants in this experiment were in a sitting position with physical activity limited to head movements and speech. During the 10-minute rest period between sessions, the participants answered questionnaires and a workload battery while the equipment was being prepared for the next session.

At the end of the experiment, the participants were debriefed about the performance of the indirect vision system and the sound localization in the stationary and moving vehicle, and any questions were answered. In addition, the participants answered a questionnaire for the subjective evaluation of the systems by the perceived performance.

4. Statistical Results

The results of the statistical analyses of the target detection and identification times, numbers, and errors, along with the analyses of the heart rate and the ratings from the questionnaires, are reported here.

4.1 Task Performance for Detection and Identification

The overall task performance was determined with a canonical correlation analysis (Pedhazur, 1982) applied to the detection and identification times and event measures, using the multivariate fitting option of the SAS[3] JMP[3] statistical software package. The dependent time measures used in the analysis are the natural logarithmic transformations of the times to detect and the times to identify after detection. The time to complete the trial, which was limited to 15 seconds, was used as the detection time for those presentations when a target was not detected; 10 seconds were used for an identification time for failures to identify after detection. The detection, identification, and correct identification events were "dummy" coded as categorical variables, with a success assigned the value of unity and a failure, the value 0. There were no false alarm detections since none of the participants reported targets on any of the runs when no targets were presented. The fixed factors of the experiment were represented as categorical variables by effect coding and the factorial interactions by the coding products. The target distance and azimuth are continuous variables computed for the time of detection. Since the experiment is within subjects with repeated measures, the subjects were represented as categorical variables by their total times to detect as a criterion scale coding. In turn, since criterion scaling is used in place of effect coding, the degrees of freedom in the analysis are corrected to account for the number of subjects.

The canonical correlation analysis is an overall statistical test and does not indicate the separate contributions of the multiple dependent variables to the differences between the factorial groupings. The structure coefficients or loadings derived from the canonical weights are measures of the correlations between the variables and the canonical variate scores. For this reason, the logarithmic time variables were analyzed with separate parametric multiple linear regressions (Pedhazur, 1982), with the Statistical Package for the Social Sciences (SPSS) 8.0. The independent variables are the same as for the canonical correlation. Similarly, the detection, identification, and correct identification events were analyzed in separate discriminant analyses (Pedhazur, 1982; Cooley & Lohnes, 1971), in which the success and failure of the event are interpreted as members of separate populations. Here the dependent variable of membership is categorical and nominal in scaling.

The validity of the multiple regression analyses depends on the satisfaction of certain requirements for the error residuals. The conditions on error distributions (normal with zero means) and variances (homoscedasticity or constant for all groupings) are satisfied when the frequency distributions for the dependent and independent variables are symmetrical. The detection and identification time distributions are skewed toward the lower values while being limited by the occurrences of elapsed time. However, the natural logarithmic transformations of the detection and identification times are close to normal and for this reason, are analyzed. The categorical codings are symmetrical as fixed factors. The continuous variable distributions of distance and azimuth are close to normal by design. While the fixed factors were blocked in presentation, the targets were

[3] not an acronym

presented in a random order by distance and azimuth resulting in serial independence of the error residuals and lack of correlation with the independent variables.

4.1.1 Overall Task Performance

The results of the canonical correlation analysis shows that the measures of task performance are significantly influenced by the vehicle movement ($p < .0001$) and vision ($p < .0001$) modes, and the interaction between the movement and vision ($p < .0001$). The whole model Wilks' lambda value of 0.1778 with a maximum canonical correlation of 84.05%, corresponds to a $p < 0.0001$ level of statistical significance (approx F = 18.192, dfn = 85, dfe = 3601).

4.1.2 Detection Times

The natural logarithms of the detection times (including the 15-second time allotted to the incomplete trials) are significantly influenced by the vehicle movement ($p < .001$) and vision ($p < .001$) treatments and by the three-way interaction among the vehicle movement, vision, and audio cueing treatments ($p < .004$). The overall model ANOVA is statistically significant (F = 87.676, dfn = 17, dfe = 748, $p < .0005$), indicating that some model coefficients are significantly different from zero. The regression model with a 81.6% correlation coefficient, accounts for 66.6% of the variance; however, since this is an overestimation of the population correlation (r-square), the adjustment for the number of model variables and sample size is 66.1%. The standard error of the estimate (square root of the residual mean square) is 0.4484. As with any multiple regression analysis, the t-statistics for the model coefficients, obtained by dividing the coefficient by its standard error, is a measure of the statistical significance of the coefficients with the standardized "Beta" coefficients for the data transformed to z-scores, which are used to compare the coefficients.

Figure 10 is a plot of the average detection times with 95% confidence intervals for the treatment conditions of vehicle movement, vision mode, and audio cueing format. The figure shows the main effects and the interactions among the three modes. The results are that on the average, the targets were detected quickest with direct viewing from the stationary vehicle without audio localization. On the average, the targets were detected sooner with direct viewing than with the HMD, and for the HMD, sooner from the stationary position than the moving vehicle.

A study of the confidence intervals plotted in Figure 10 suggests that for the HMD, there are insignificant differences between the cued and non-cued times for the moving and stationary modes. In addition, there are insignificant differences for the direct vision among the moving cued and non-cued modes and the cued stationary. The results suggest that the three-way interaction is attributable to the significant difference of the non-cued, stationary mode for the direct vision from the rest of the treatments. An application of Scheffé's *post hoc* two-way comparison test shows that the detection times (natural logarithms) for this treatment mode are significantly less (Scheffé's F value = 107.013, df = 1, dfe = 748, $p < .05$) than those for the remaining modes. A study of the data shows no outliers as a source of this difference.

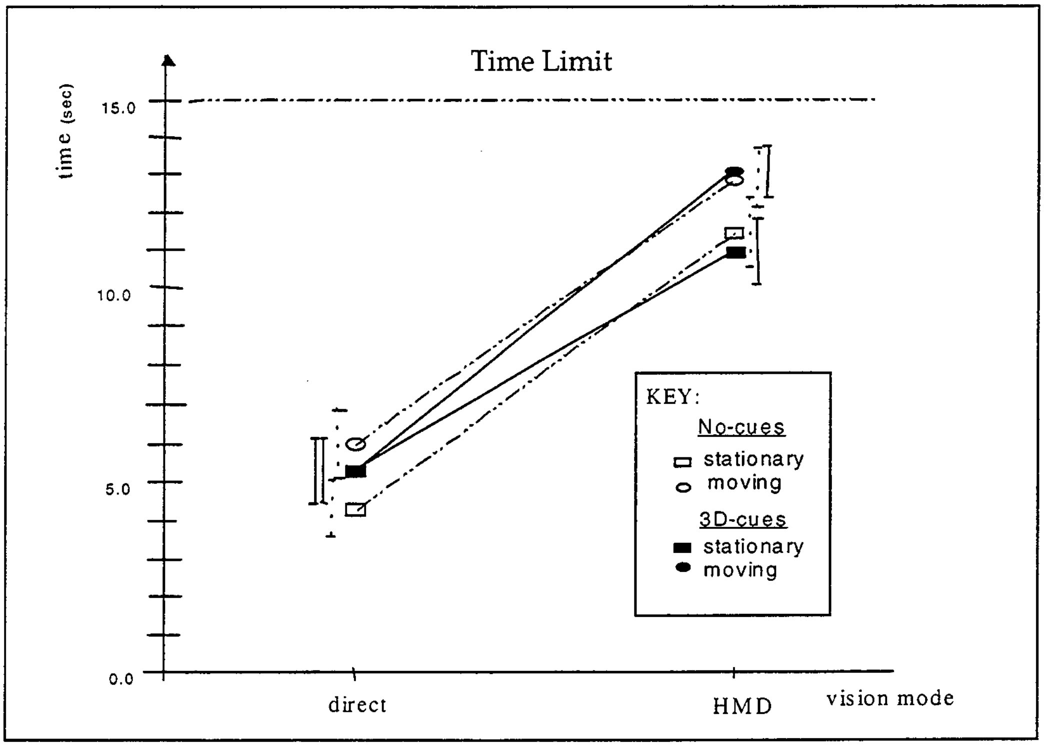

Figure 10. Average Detection Times (including elapsed time) With 95% Confidence Intervals.

4.1.3 Detection Events

The detection events are significantly influenced by the vehicle movement ($p < .001$) and vision ($p < .001$) modes and their interaction ($p < .001$). The discriminant model with a 86.7% correlation coefficient, accounts for 75.3% of the variance (adjusted r-square is 71.7%; standard error of the estimate is 0.01515). The F statistic for the overall model ANOVA is significant (F = 10.642, dfn = 14, dfe = 49, $p < .001$).

Figure 11 is a plot of the number of detections as a function of the conditions of vehicle movement, vision modes, and cueing format. The results are that more targets were detected with direct viewing than with the HMD and for the HMD from the stationary position than the moving vehicle. An application of the Scheffé's *post hoc* two-way comparison test shows that the number of detections for the moving vehicle with the HMD are significantly less (Scheffé's F-value = 12.972, dfn = 1, dfd = 49, $p < .05$) than those for the remaining modes. Although there is a trend for more targets being detected with direct viewing from the stationary vehicle without audio cueing, the audio cueing increased the number of targets detected in all other treatments.

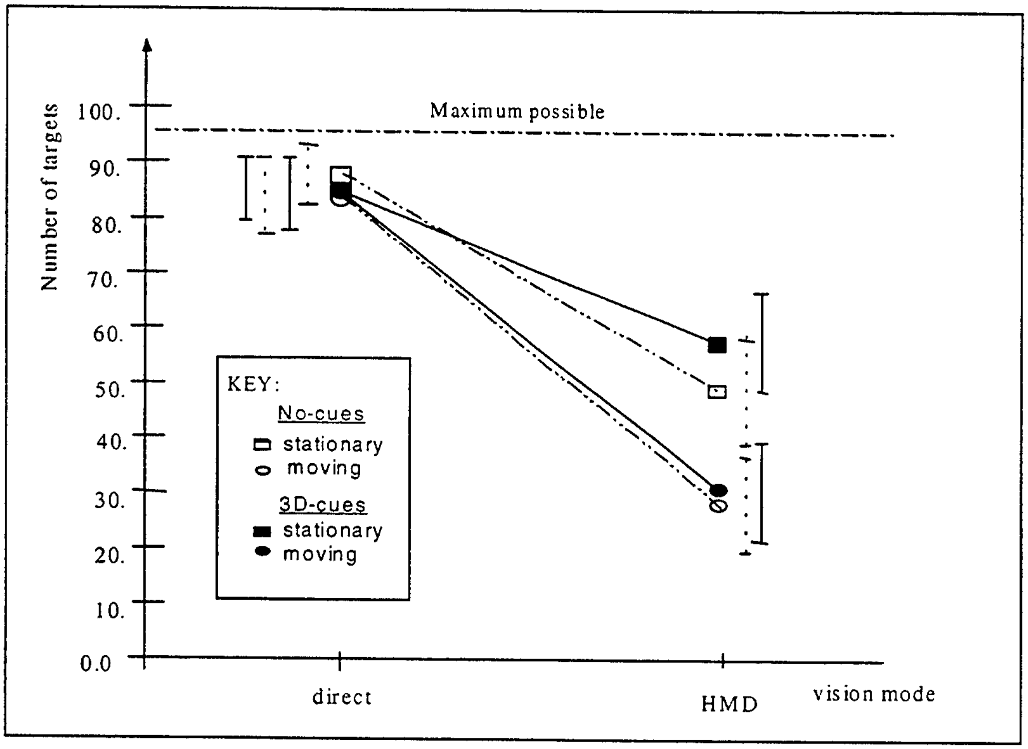

Figure 11. Total Number of Targets Detected With 95% Confidence Intervals.

4.1.4 Identification Times

The identification times (including the 10-second time allotted to the incomplete trials) are significantly influenced by the vehicle movement ($p < .001$) and vision ($p < .001$) modes and their interaction ($p < .001$). The regression model with a 68.2% correlation coefficient, accounts for 46.5% of the variance (adjusted r-square is 45.7%). The standard error of the estimate is 0.3626. The F statistic for the overall model ANOVA is significant (F = 38.379, dfn = 17, dfe = 748, $p < .001$).

Figure 12 is a plot of the average identification times as a function of the treatment conditions of vehicle movement, vision modes, and cueing format. Comparing all treatments, the fastest identifications were made with direct viewing from the stationary vehicle. Considering the vision modes, the targets were identified faster with direct viewing than with the HMD. An application of Scheffé's *post hoc* two-way comparison test shows that the identification times (natural logarithms) for the moving vehicle with the HMD are significantly greater (Scheffé's F-value = 22.754, dfn = 1, dfd = 748, $p < .05$) than those for the remaining modes. Audio cueing shows a trend for decreased identification times in all treatments except for the HMD from the moving vehicle.

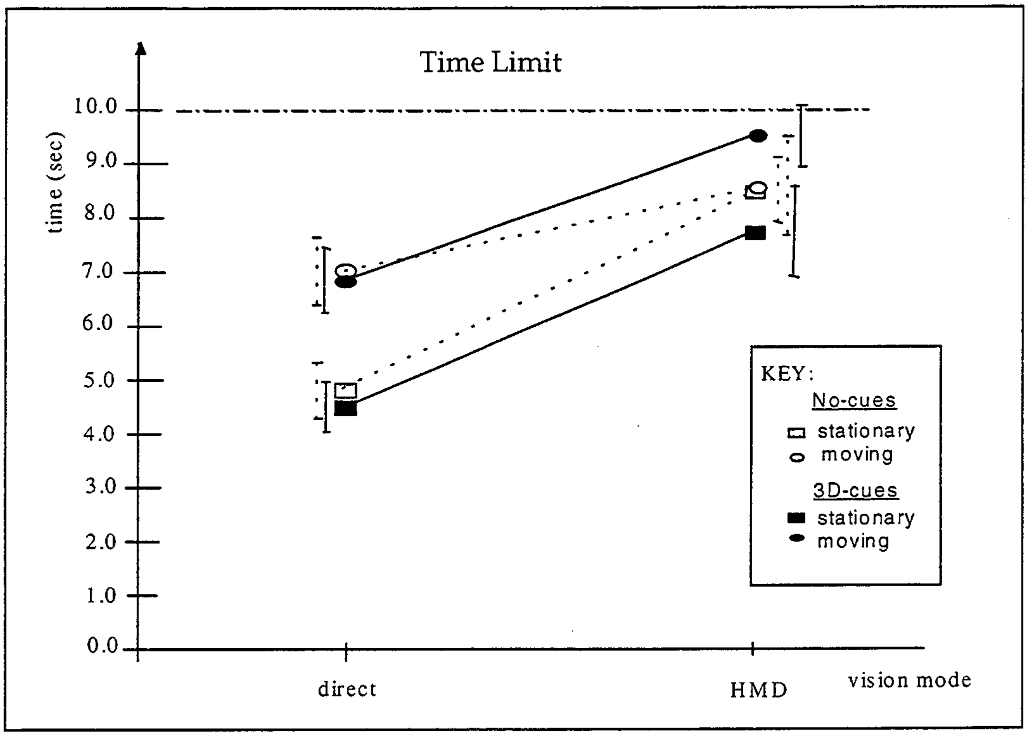

Figure 12. Average Identification Times (including elapsed time) With 95% Confidence Intervals.

4.1.5 Identification Events

The identifications are significantly influenced by the vehicle movement ($p < .001$) and vision ($p < .001$) modes, and less so by their interaction ($p < .013$). The discriminant model with a 90.5% correlation coefficient accounts for 82.0% of the variance (adjusted r-square is 79.3%); the standard error of the estimate is 0.0233. The F statistic for the overall model ANOVA is highly significant (F = 15.977, dfn = 14, dfd = 49, $p < .001$). Figure 13 is a plot of the number of identifications as a function of the treatment conditions of vehicle movement, vision, and cueing mode. The figure shows the main effects and the interactions among the experimental conditions. The results are that more targets were identified with direct viewing than with the HMD and from the stationary position than the moving vehicle. More targets were identified with direct viewing from the stationary vehicle than in the other conditions. An application of Scheffé's *post hoc* two-way comparison test shows that on the number of identifications for the moving vehicle with the HMD are significantly less (Scheffé's F-value = 19.594, dfn = 1, dfd = 49, $p < .05$) than those for the remaining modes.

4.1.6 Correct Identifications

The statistics for the targets correctly identified follow closely those for the identifications. The correct identifications are significantly influenced by the vehicle movement ($p < .001$) and vision ($p < .001$) modes. The discriminant model with a 87.5% correlation coefficient accounts for 76.6% of the variance (adjusted r-square is 73.2%); the standard error of the estimate is 0.0244. The F statistic for the overall model ANOVA is highly significant (F = 11.513, dfn = 14, dfd = 49, $p < .001$). The numbers of correct identifications plotted in Figure 14 are significantly influenced by the vehicle movement and vision modes. The results are that more targets were identified correctly with direct viewing than with the HMD and from the stationary position than the moving vehicle. More targets were identified correctly with direct viewing from the stationary vehicle than in the other conditions.

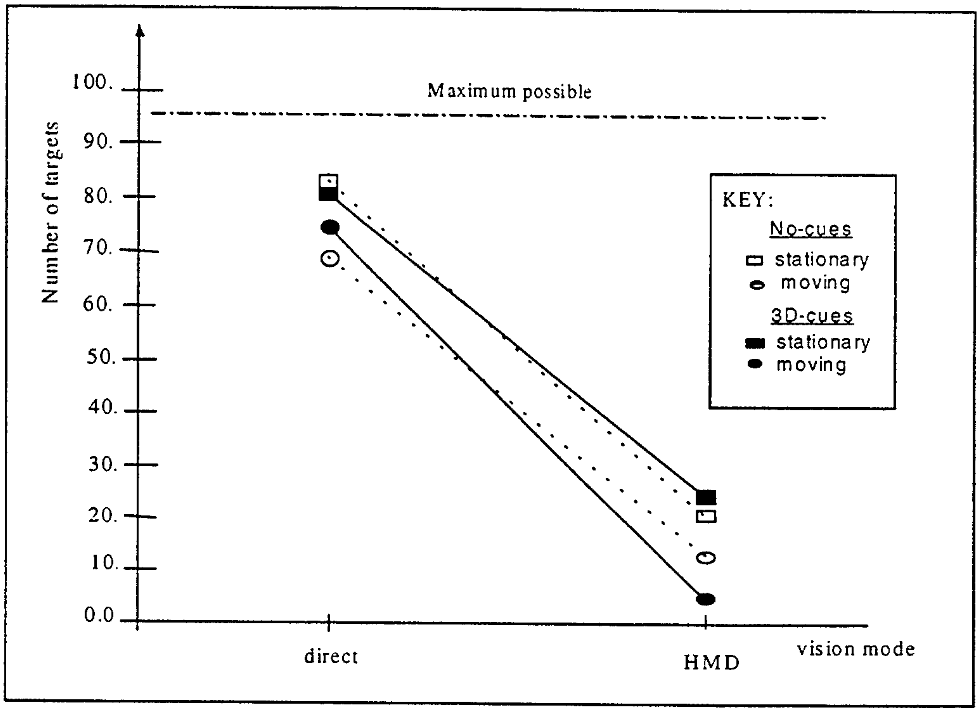

Figure 13. Total Number of Targets Identified Per Treatment.

A study of the error residuals for the regression analyses listed shows that the requirements for parametric analysis are met in all cases. The residuals for the effect groupings appear normally distributed with zero means and nearly zero skewness and kurtosis, satisfy homoscedasticity with constant variance, are serially independent, and are not correlated to the independent effects. The histograms and normal probability plots of the standardized residuals for the dependent variable are closely normal in distribution. Similarly, the partial regression scatter plots of the residuals plotted against the independent variables show the points scattered in a horizontal band with no apparent systematic features, as would be expected if no relations remained after regression.

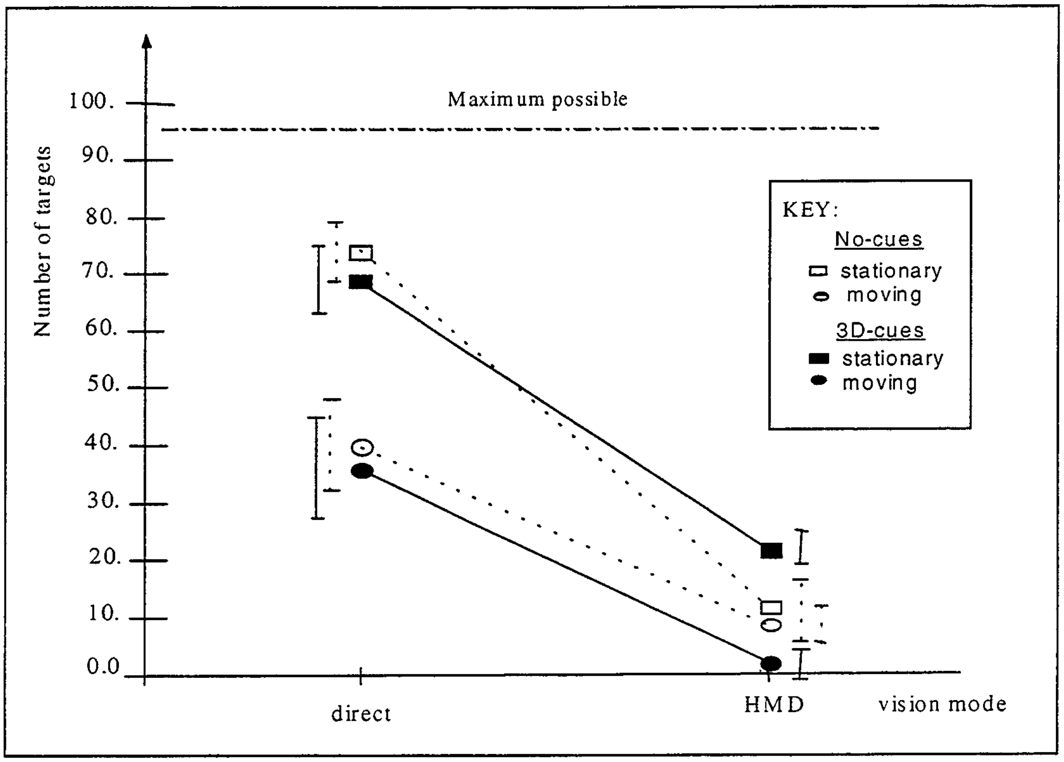

Figure 14. Total Number of Targets Identified Correctly Per Treatment.

4.2 Heart Rate

Heart rate was not significantly influenced by the treatments, as determined by a univariate RM ANOVA. The average heart rate experienced by the participants was 79.6 beats per minute. The heart rates were measured at the end of the trial runs for each block.

4.3 Subjective Questionnaires

The scores for the questionnaires are analyzed for (a) the attention allocation loading factors for the detection and identification tasks, (b) the NASA-TLX of perceived workload, (c) Kennedy's subjective estimation of motion sickness, and (d) Selcon and Taylor's SART. The attention allocation loading factors are measures of sensory, cognitive, and motor channel loading, which are particular to the tasks as experienced by the participants. The workload battery, motion sickness, and SA ratings are measures of the subjectively perceived states by the participants as influenced by the task and environment.

Although the overall significance for each questionnaire is determined by the statistical analysis of the factorial components, the statistical study of the scores for the questionnaire is of interest. However, a study of the rating scores for the questionnaires shows that in many cases, the data for the treatment effects do not satisfy the conditions for a parametric ANOVA. For many questions, the distributions are not normal or the variances are not homogeneous. This is especially true for the motion sickness questionnaire, in which most ratings were assigned a zero score for all but the treatment of the moving vehicle with the HMD, and several participants assigned a value of zero to this condition. For this reason, the statistical significance of the scores is analyzed with the NP Friedman ANOVA by ranks for matched samples, following ranking of the rating scores.

The statistical approach used to analyze the score data is different for each questionnaire. The scores for the loading factors for the detection and identification tasks are analyzed in separate statistical tests for the sensory, cognitive, and motor channels. The factors are estimates of the task loading on the channels as separate components of an attention resource model of human performance.

The scores for the NASA-TLX workload battery are analyzed as an overall sum, the sums for the demand and interaction, and the component scores. This is because the separate components represent different kinds of workload. Here, the mental, physical, and temporal dimensions measure the demands placed on the participant, while the effort, frustration, and performance dimensions relate to the interaction with the task.

Similar comments apply to the analyses of the motion sickness ratings. An overall estimation of motion sickness formed from the sum of the ratings for the components is statistically analyzed in an NP ANOVA. Further, the components represent degrees of motion sickness extending from general discomfort to extreme nausea and are analyzed in separate statistical tests.

Again, similar comments apply to the analysis of the SART. The scores for the demands upon attentional resources and those for the support (supply) of attentional resources are measures of the workload used to maintain SA. An overall rating (R) is obtained by the difference between the sum of the components for the supply (S) and the demand (D) added to those for understanding of the situation (U), i.e., $R = S - D + U$. For this reason, estimates of the overall rating, along with the sums of the demand, support, and understanding scores are analyzed separately, as are the scores for the separate questions.

4.3.1 Attentional Allocation Factors

The allocations of the attentional resources to the auditory, visual, cognitive, and psychomotor processing channels are significantly different for the treatments, as estimated by the attention allocation loading factors. This is true of the auditory and psychomotor channels for the detection task, and the auditory channel for the identification task.

4.3.1.1 Detection Task

Figure 15 shows a factorial component loading diagram for the detection task following reduction to two components with a factor analysis using principal component analysis as the extraction method (69.559% total variance explained), and Varimax rotation with Kaiser normalization. Considering the loading diagram to represent a state space for the attention loading, the first factorial component corresponds to visual and cognitive processing, while the second component corresponds to motor responses. Here, a study of the rotated component weight matrix shows that the first component is dominated by the visual (0.877, 0.114) and cognitive (0.889, 0.102) channels, while the second component is dominated by the psychomotor channel (-0.024, 0.846). The auditory channel (0.226, 0.657) has elements of both components.

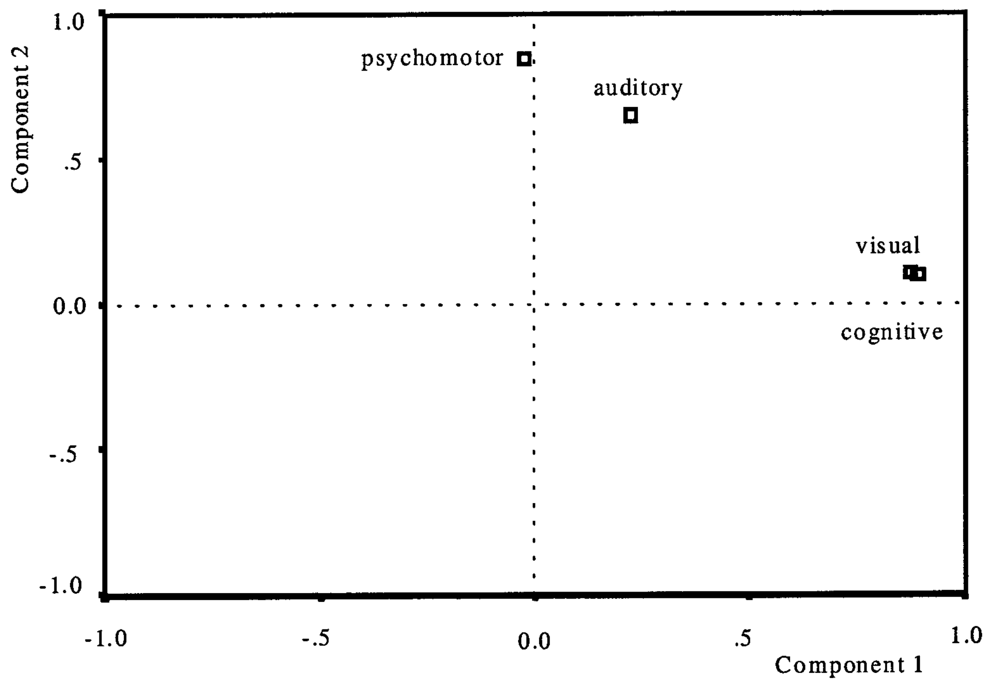

Figure 15. Factorial Component Plot in Rotated Space for Allocation of Attention for Detection.

Application of an NP RM Friedman ANOVA test by ranks shows that the first factorial component varies significantly with treatments ($p < .009$, chi-square = 18.792, df = 7, N =8). Figure 16 is an exploratory data analysis (EDA) "box-and-whisker" plot (Velleman & Payne, 1992) of the first component for each of the treatments.The figure shows that the box plots for the stationary treatments are heavily skewed with one outlier and no extreme values. For an EDA, the boxplot for a distribution will show the median, the "hinges" (first and third quartiles), and the maximum and minimum values that are not outliers or extreme values. Any outlier values of the distribution are marked by an open circle (o) and the extremes are marked by an asterisk (*). Values more than 1.5

times the box lengths (interquartile range) from the quartiles are designated as outliers and values more than three box lengths are designated as extremes.

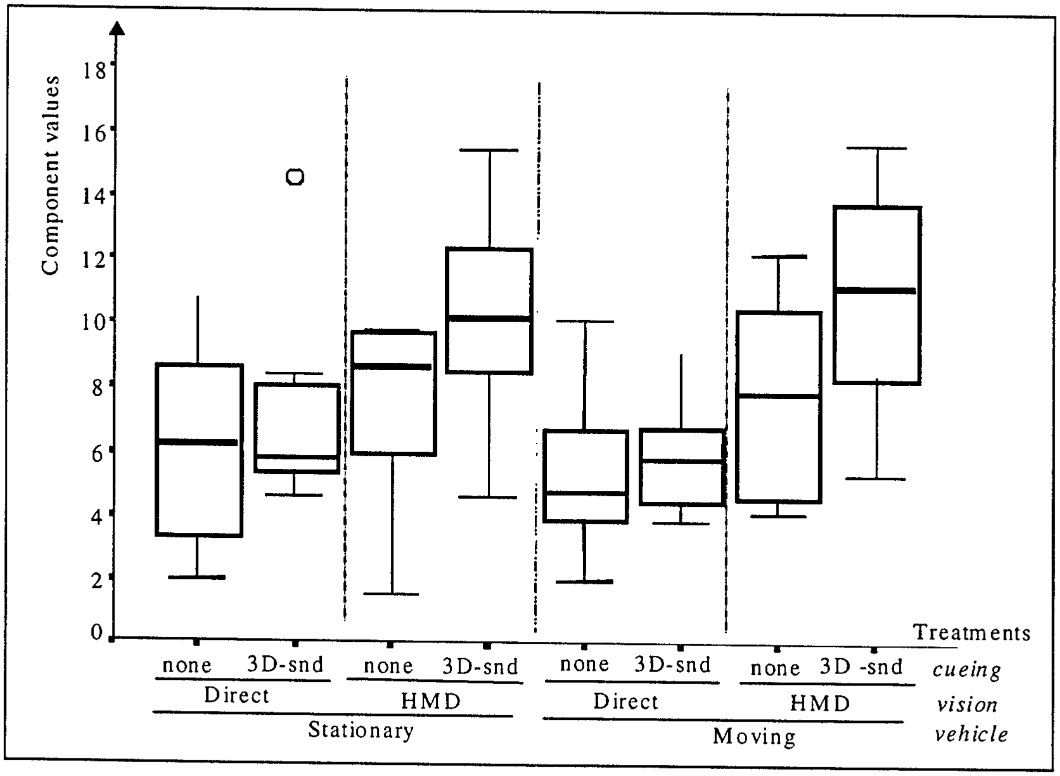

Figure 16. Box Plots for the First Factorial Component of the Detection Attention Allocations.

As a confirmation of this result, the separate applications of the univariate NP RM Friedman ANOVA test by ranks shows statistically significant differences among the treatments for the psychomotor channel (chi-square statistic = 28.717, df = 7, $p < 0.001$) and auditory channel (chi-square statistic = 49.800, df = 7, $p < 0.001$). A Scheffé pair-wise comparison test for the contrast of rank means shows the source of these differences. Significant higher attention was allocated to the psychomotor channel with the HMD compared to that with direct viewing (Scheffé test statistic = 24.0, df = 7, $p < .01$). Significantly higher allocations occurred for the auditory channel with sound localization (Scheffé test statistic = 42.667, df = 7, $p < .001$) compared to that with no cues.

The box plots of Figures D-1 through D-4 in Appendix D show the visual, cognitive, auditory, and psychomotor channel loading scores. For reference, the figures show the verbal anchors for the equivalent behavioral functions that correspond to the loading factors (see questionnaire in Appendix A). The figures show that the increase in average loading with the HMD compared to that for direct vision is generally true for all channels. While the allocation increase is statistically significant for the psychomotor channel, the plots show increasing trends with the HMD for all remaining channels. For the cognitive channel, the effect is level for all treatments except the audio cueing in the moving vehicle where the cognitive loading is reduced for direct vision but markedly increased with the HMD. Finally, the significant increase in auditory attention caused by the audio cueing is coupled with an increasing trend with the HMD.

4.3.1.2 Identification Task

Figure 17 shows a factorial component loading diagram for the allocations to the four channels for the identification task after reduction to two components with a factor analysis using principal component analysis as the extraction method (69.113% total variance explained), and Varimax rotation with Kaiser normalization. A study of the rotated component weight matrix shows that the visual (0.878, 0.025) and cognitive (0.809, 0.105) channels dominate one component, while the auditory channel (0.240, 0.845) dominates the other component, and the psychomotor (0.466, -0.595) is divided between both components.

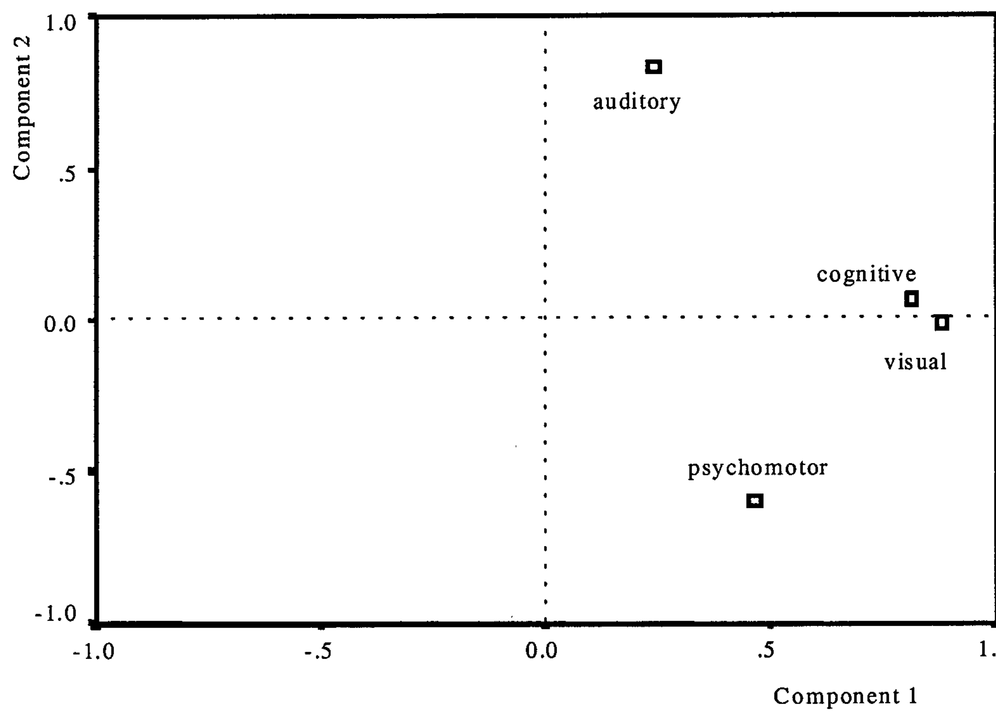

Figure 17. Factorial Component Plot in Rotated Space for Allocation of Attention for Identification.

Application of an NP RM Friedman ANOVA test by ranks shows that the second factorial component varies significantly with treatments (chi-square = 24.458, df = 7, $p < .001$) but not the first. Figure 18 shows an EDA box plot of the second component for the treatments. As a confirmation of these results, the separate applications of the NP RM Friedman ANOVA test by ranks shows statistically significant higher loadings for the auditory channel (chi-square statistic = 45.798, df = 7, $p < 0.001$) with sound localization (Scheffé test statistic = 35.042, df = 7, $p < .001$). The box plots of Figures E-1 through E-2 show the loading scores for the visual, cognitive, auditory, and psychomotor channels. The plots show that the attention loading is in the main level across vision modes. The significant increase in auditory attention is caused by the audio cueing; however, there is a trend increase in psychomotor attention with the HMD compared to that for direct vision.

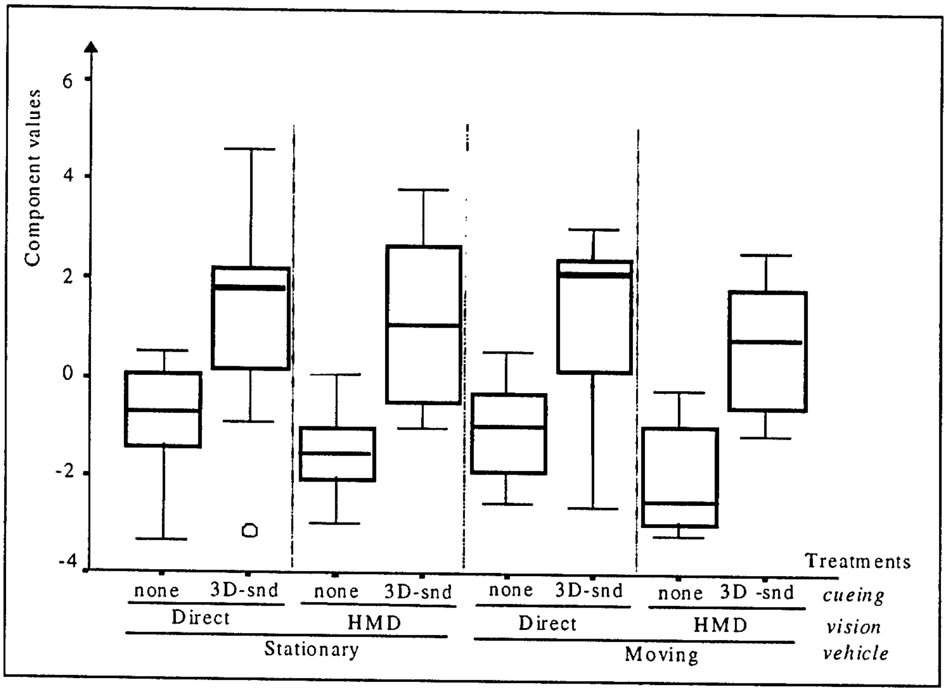

Figure 18. Box Plots for the Second Factorial Component of the Identification Attention Allocations.

4.3.2 NASA Task Loading Index (TLX) Workload Battery

As determined by analysis of the first factorial component, the perceived workload is significantly increased by the use of the HMD. Figure 19 shows a factorial component loading diagram for the six TLX scales after reduction to two components with a factor analysis using principal component analysis as the extraction method (76.953% total variance explained) and Varimax rotation with Kaiser normalization. As noted in the key on the figure, the TLX scales are shape coded by their status as task demand or interaction. Considering the loading diagram to represent a state space for the perceived workload, the first factorial component corresponds to task demand while the second component corresponds to interaction. Here, a study of the rotated component weight matrix shows that the first component is dominated by the physical demand (0.825, 0.041) while the second component is dominated by the task effort (0.126, 0.929). The mental (0.704, 0.432) and temporal (0.793, 0.387) demands and task performance (0.711, 0.525) and frustration (0.516, 0.739) have elements of both components.

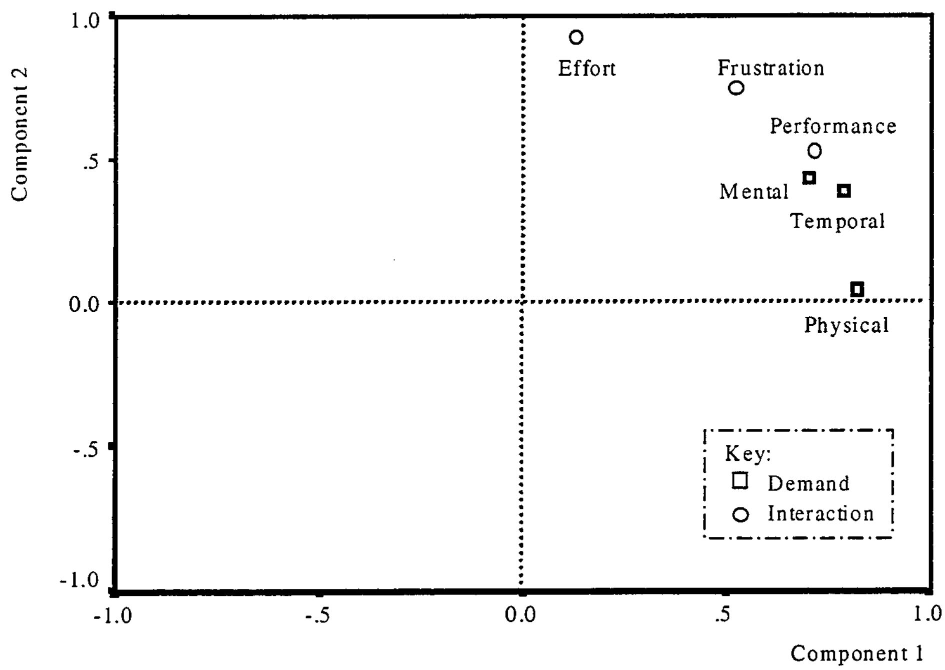

Figure 19. Factorial Component Plot in Rotated Space for TLXs.

Figure 20 shows EDA box plots of the first component for the viewing treatments. The plots show the distributions to be fairly normal with closely equal variances. A univariate RM ANOVA test of within-subjects effects is significant by visual treatments ($p < .001$, F = 50.036, df = 1, error df = 7); however, the other treatments and interactions are not significantly different from each other.

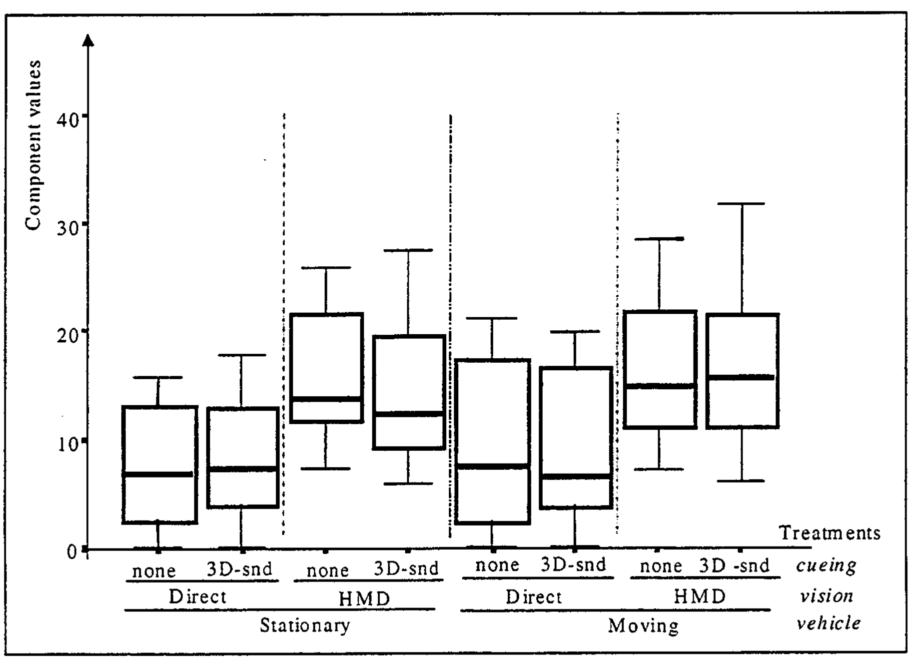

Figure 20. TLX First Factorial Component Box Plots.

The total workload is significantly greater for the HMD than for direct vision. Figure 21 shows EDA box plots of the sum of the workload scores for the viewing treatments. The univariate RM ANOVA test of within-subjects effects is significant by visual treatments ($p < .001$, $F = 43.862$, df = 1, error df = 7); however, the other treatments and interactions are not significantly different from each other. Similar comments apply to the demand and interaction sums and component scores.

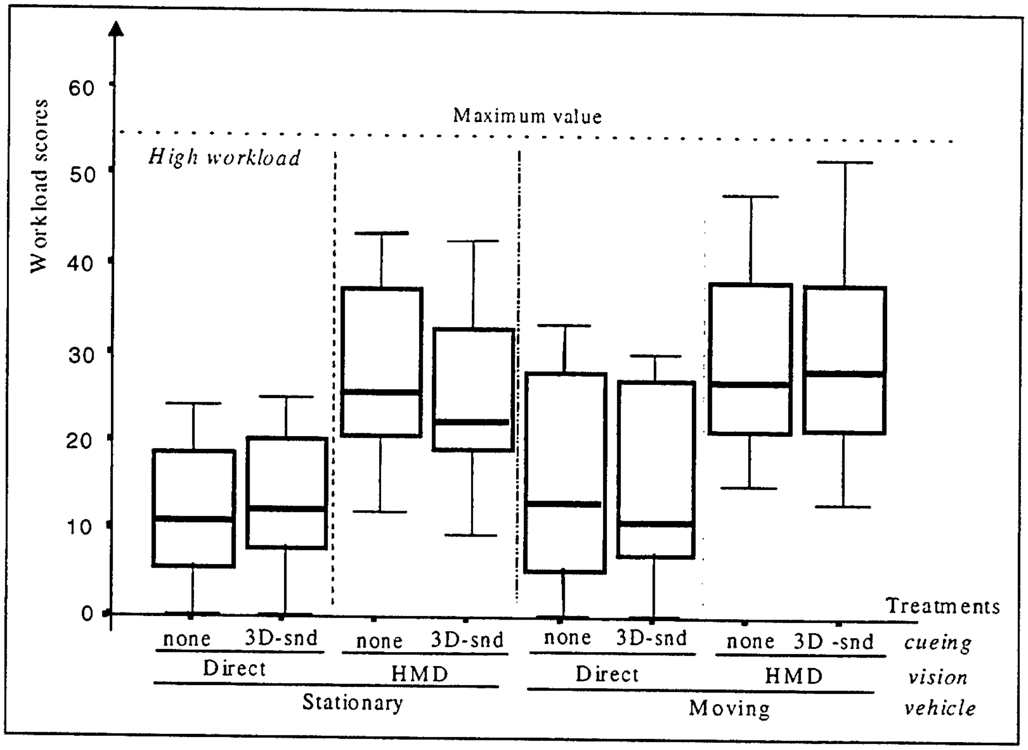

Figure 21. TLX Workload Sum Box Plots.

The sum of the demand workload scores is significantly greater for the HMD than for direct vision. Figure 22 shows EDA box plots of the demand sum for the viewing treatments. Here, the univariate RM ANOVA test of within-subjects effects is significant by visual treatments ($p < .001$, $F = 30.322$, df = 1, error df = 7); however, the other treatments and interactions are not significantly different from each other. Application of the NP RM Friedman ANOVA by ranks shows this significant difference for the demand scores. A Scheffé pair-wise comparison test for the contrast of rank means shows that these differences are primarily attributable to the visual treatments. This is true for the mental demand (chi-squared statistic = 27.956, df = 7, $p < .001$; Scheffé's test value = 25.523, df = 7, $p < .001$), physical demand (chi-squared statistic = 23.012, df = 7, $p < .002$; Scheffé's test value = 19.260, df = 7, $p < .01$), and temporal demand (chi-squared statistic = 25.604, df = 7, $p < .001$; Scheffé's value = 23.010, df = 7, $p < .01$). Figures F-1 through F-3 are box plots for these workload components and demonstrate the increase in workload demand with the HMD. As can be seen from the figures, the distributions are far from normal with non-homogeneous variances.

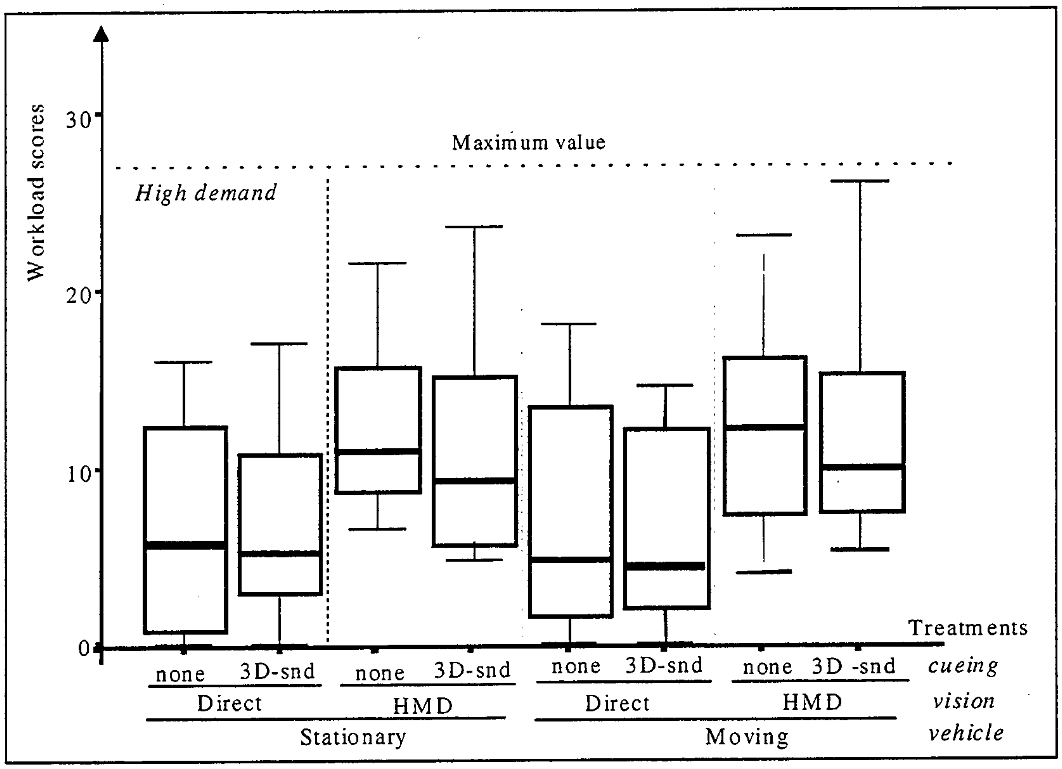

Figure 22. TLX Demand Sum Box Plots.

The sum of the interaction workload scores is significantly greater for the HMD than direct vision. Figure 23 shows EDA box plots of the interaction sum for the viewing treatments. Again, the univariate RM ANOVA test of within-subjects effects is significant by visual treatments ($p < .001$, F = 30.614, df = 1, error df = 7); however, the other treatments and interactions are not significantly different from each other. Application of the NP RM Friedman ANOVA by ranks shows that this is true for the interaction scores: effort (chi-squared statistic = 44.767, df = 7, $p < .001$; Scheffé's test value = 37.500, df = 7, $p < .001$), performance (chi-squared statistic = 28.744, df = 7, $p < .001$; Scheffé's test value = 24.00, df = 7, $p < .001$), and frustration level (chi-squared statistic = 33.153, df = 7, $p < .001$; Scheffé's test value = 28.711, df = 7, $p < .001$). Figures F-4 through F-7 are box plots for these workload components and demonstrate the increase in workload interaction with the HMD. As can be seen from the figures, the distributions are far from normal with non-homogeneous variances, as would be expected from the summation data.

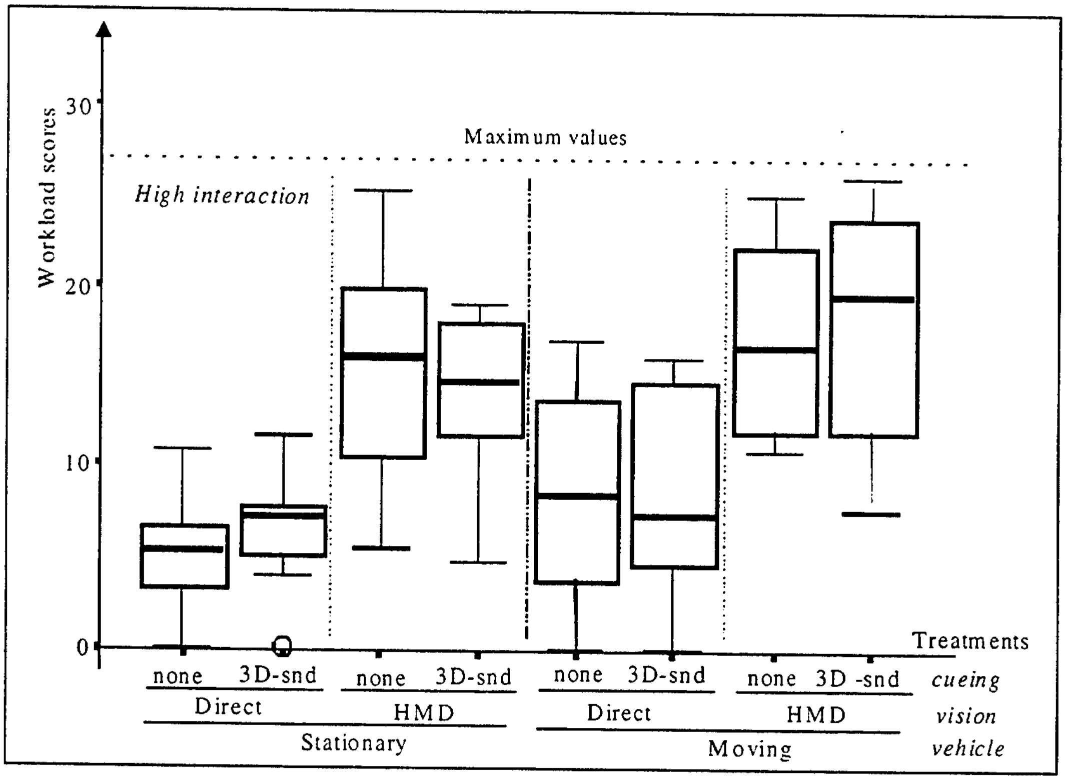

Figure 23. TLX Task Interaction Sum Box Plots.

4.3.3 Kennedy's Subjective Estimation of Motion Sickness

As determined by analysis of the first factorial component, motion sickness is significantly greater for the HMD while participants are in the moving vehicle. Figure 24 shows a factorial component loading diagram for the 16 motion sickness scales after reduction to three components with a factor analysis using principal component analysis as the extraction method (78.240% total variance explained), and Varimax rotation with Kaiser normalization. As noted in the key on the figure, the scales are shape coded by their status as nausea, oculomotor, or disorientation symptoms (Kennedy et al., 1992); those scales used in multiple symptoms are only coded for one symptom. A study of the rotated component matrix for the factorial plot of Figure 24 suggests that the first factorial component reflects dizziness and cognitive impediment; the second component reflects physical impediment, and the third component reflects ocolomotor difficulties. Although not an exact mapping to the disorientation, nausea, and oculomotor symptoms determined by Kennedy et al. (1992), the interpretations are similar.

Figure 25 shows EDA box plots of the first factorial component for the treatments. The plots show the distributions to be practically zero for all treatments except for moving with the HMD, and heavily skewed with outliers for these conditions. An NP RM Friedman ANOVA test by ranks is significant for the component across treatments (chi-square = 27.392, df = 7, N = 8, $p < .001$).

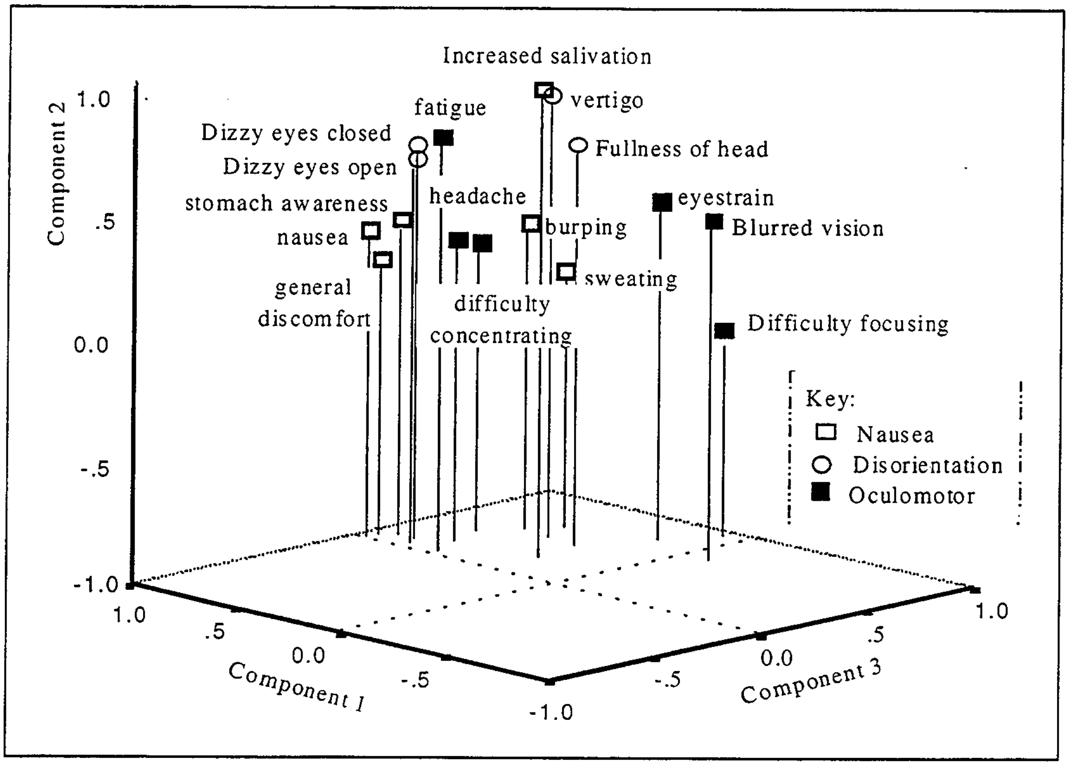

Figure 24. Motion Sickness Factorial Component Plot in Rotated Space.

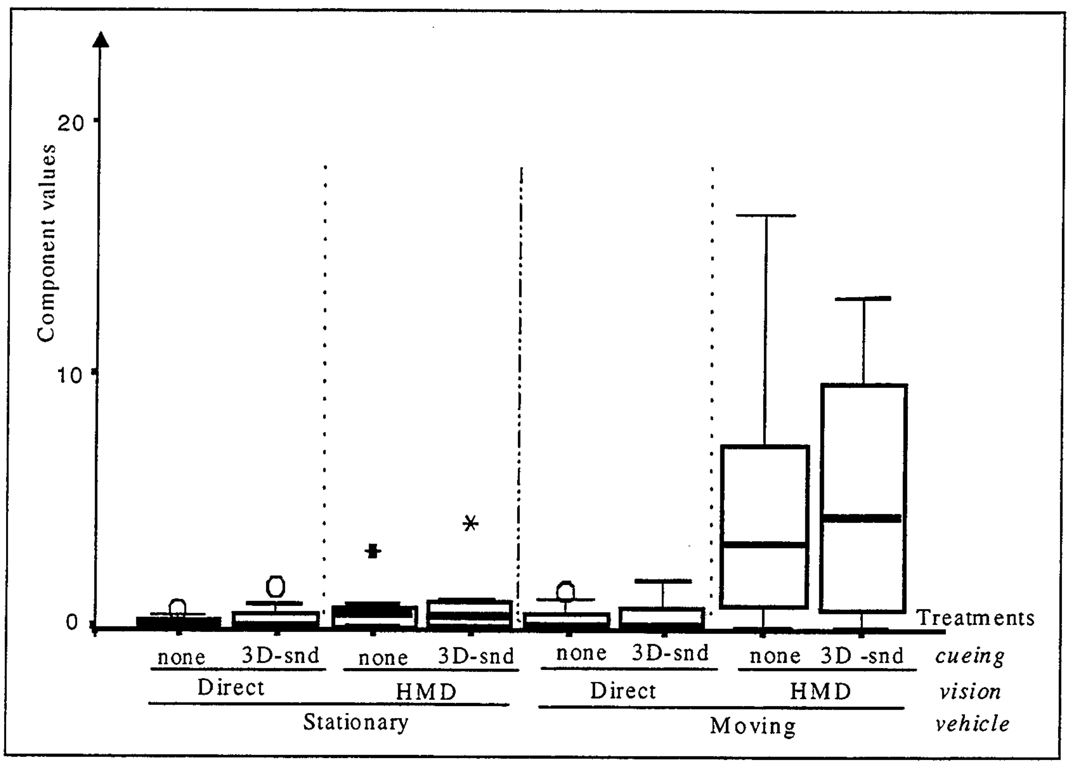

Figure 25. Motion Sickness First Factorial Component Box Plots.

The total severity motion sickness is significantly greater for the moving vehicle with the HMD. Figure 26 shows EDA box plots of the total severity as a function of the treatment. The distributions are largely skewed toward low values except for the treatments of moving with the HMD. An NP Friedman ANOVA test by ranks applied to the total severity shows significant differences across treatments (chi-square = 34.893, df = 7, N = 8, $p < .001$). A Scheffé pair-wise comparison test for the contrast of rank means shows that this difference is attributable to the HMD in the moving vehicle (Scheffé's test statistic = 22.222, df = 7, $p < .01$).

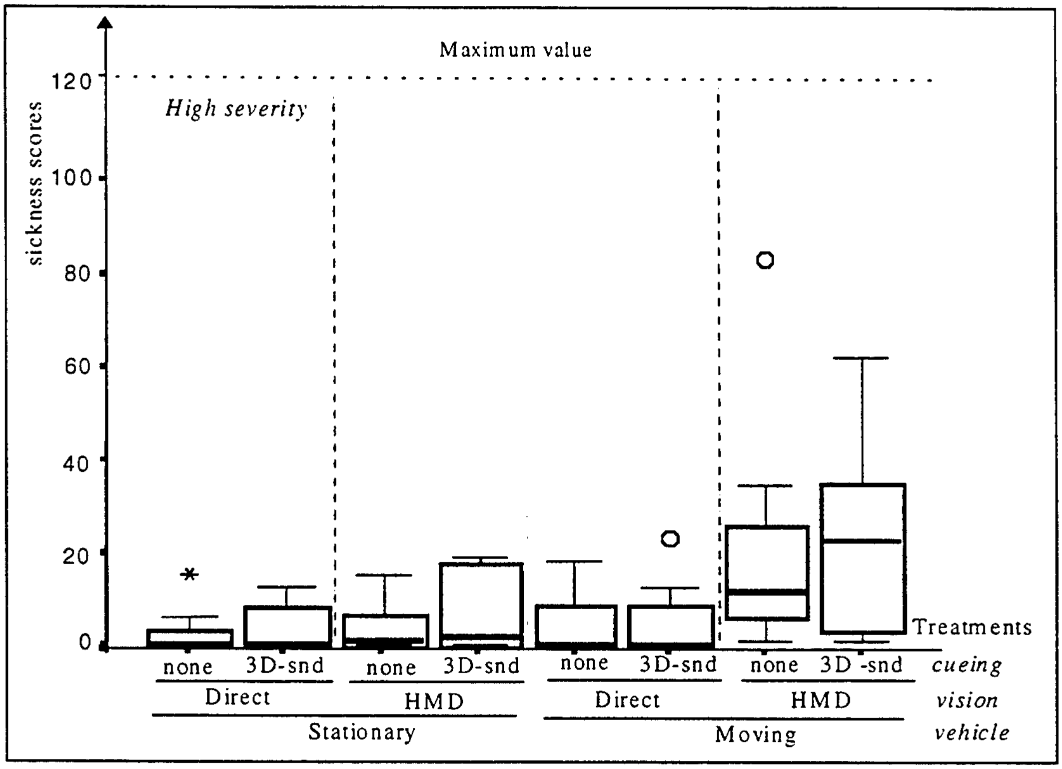

Figure 26. Motion Sickness Total Severity Box Plots.

Similar comments apply to the nausea, oculomotor, and disorientation symptom sums for which box plots are plotted in Figures 27, 28, and 29. Again, the distributions are largely skewed toward low values except for the HMD in the moving vehicle. Friedman tests show significant differences among treatments for the nausea symptom (chi-square = 35.735, df = 7, N = 8, $p < .001$), oculomotor symptom (chi-square = 32.101, df = 7, N = 8, $p < .001$), and the disorientation symptom (chi-square = 20.824, df = 7, N = 8, $p < .004$). Again, application of Scheffé pair-wise comparison tests shows that these differences are attributable to the HMD in the moving vehicle, at least for the nausea symptom (Scheffé's test statistic = 21.125, df = 7, $p < .01$) and oculomotor symptom (Scheffé's test statistic = 18.000, df = 7, $p < .02$).

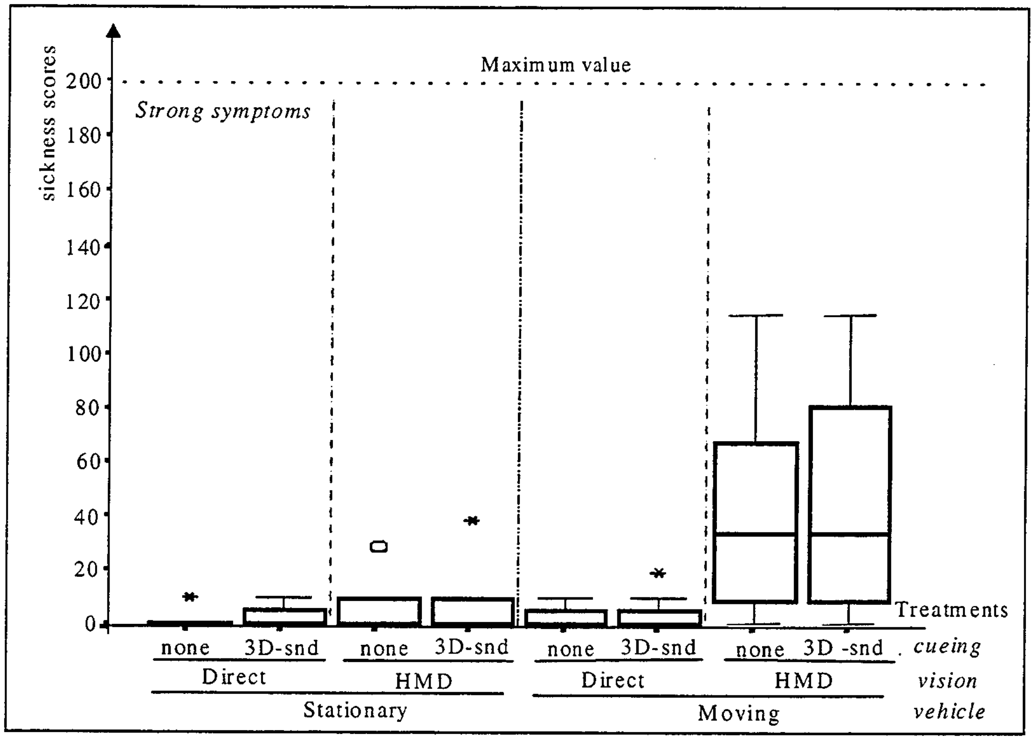

Figure 27. Motion Sickness Nausea Symptom Box Plots.

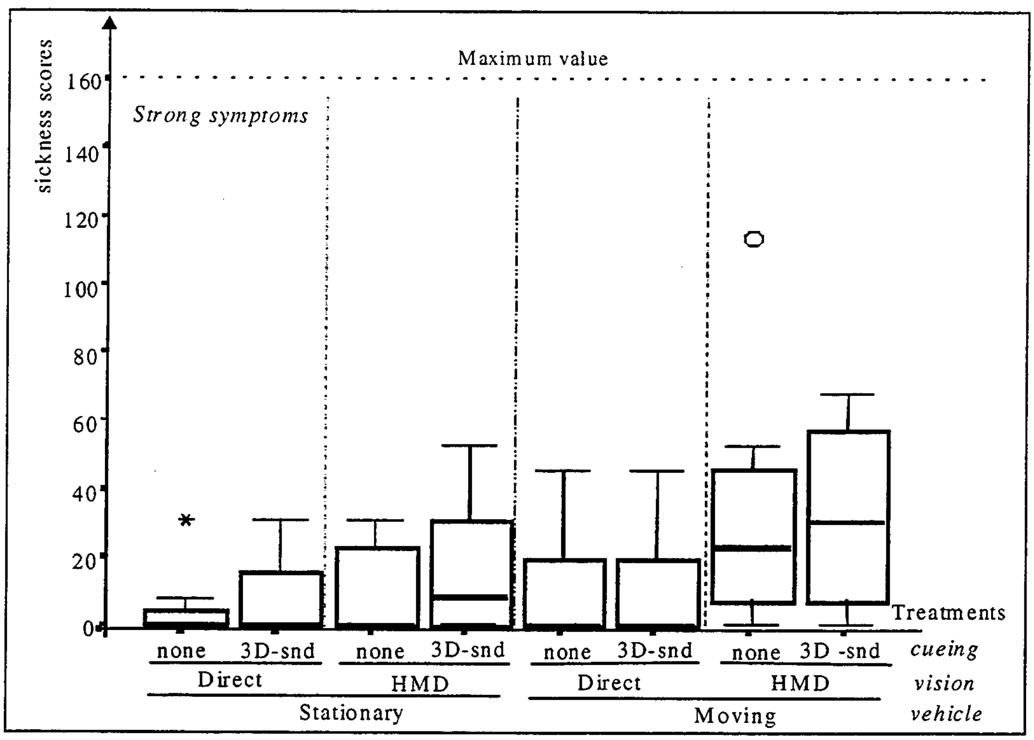

Figure 28. Motion Sickness Oculomotor Symptom Box Plots.

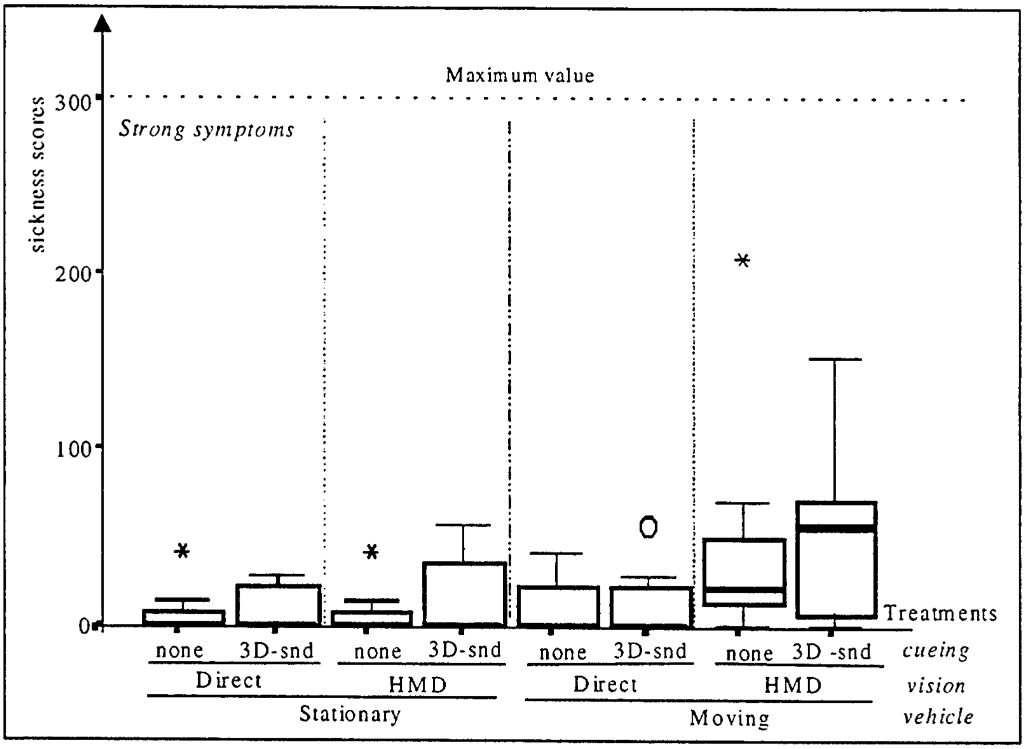

Figure 29. Motion Sickness Disorientation Symptom Box Plots.

A review of the 16 motion sickness ratings shows that the distributions are largely skewed from normality with outliers; this is especially true for the direct viewing treatments but also, in many cases, for the other treatments. The ratings show significant general discomfort (chi-square statistic = 35.238, df = 7, $p < .001$) for the moving vehicle with the HMD (Scheffé test value = 15.125, df = 7, $p < .05$). Six of the eight participants reported discomfort with the HMD in the moving vehicle, while the remaining two did not. Figure 30 is a box plot of the general discomfort ratings as a function of the treatments, which shows significant discomfort for the moving vehicle with the HMD. Although the plot shows an incident of slight discomfort for the stationary vehicle with the HMD, no discomfort was reported for the direct vision treatments.

For the moving vehicle with the HMD, significant increases are reported for nausea ($p < .001$), stomach awareness ($p < .001$), dizziness with eyes open ($p < .003$) and closed ($p < .003$), sweating ($p < .009$), burping ($p < .023$), and difficulty in concentration ($p < .024$). Although the box plots for these measures show significant increases in incidences for the moving vehicle with the HMD, none are reported for the other treatments except for sweating and concentration. Several participants reported incidences of difficulty in concentration for direct viewing in the moving vehicle, and one participant reported slight difficulty with the HMD in the stationary vehicle. In contrast, some incidences of sweating were reported during all treatments possibly because of the relatively warm weather; however, more incidents were reported for the HMD with the moving vehicle.

The remaining components of motion sickness show statistically insignificant higher ratings for the treatment of the HMD in the moving vehicle with fewer participants reporting incidences. For this treatment, several participants reported incidences of fatigue, salivation, fullness of head, and vertigo. For all treatments, some incidences were reported of headaches, eye strain, difficulty in focusing, and blurred vision. These latter measures may just as well have been caused by a demanding visual search with optical equipment on a sunny day; however, more incidents were reported for the HMD with the moving vehicle.

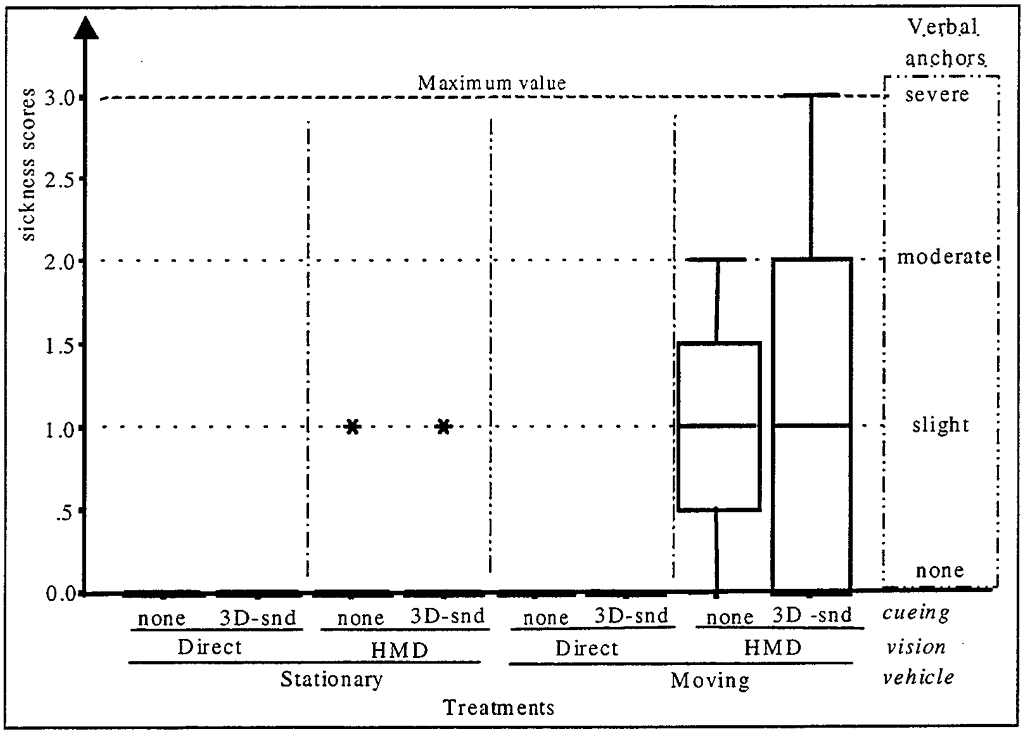

Figure 30. Motion Sickness General Discomfort Box Plots.

4.3.4 Selcon & Taylor's Situation Awareness Rating Technique (SART)

Situation awareness is significantly influenced by the visual treatments as determined by analysis of the first factorial component. Figure 31 shows a factorial component loading diagram for the ten scales after reduction to three components with a factor analysis using principal component analysis as the extraction method (78.030% total variance explained), and Varimax rotation with Kaiser normalization. As noted in the key on the figure, the scales are shape coded by their status as SA demand, supply, or understanding. A study of the rotated component matrix for the factorial plot of Figure 31 suggests that the first factorial component reflects the demand, the second component understanding, and the third component supply.

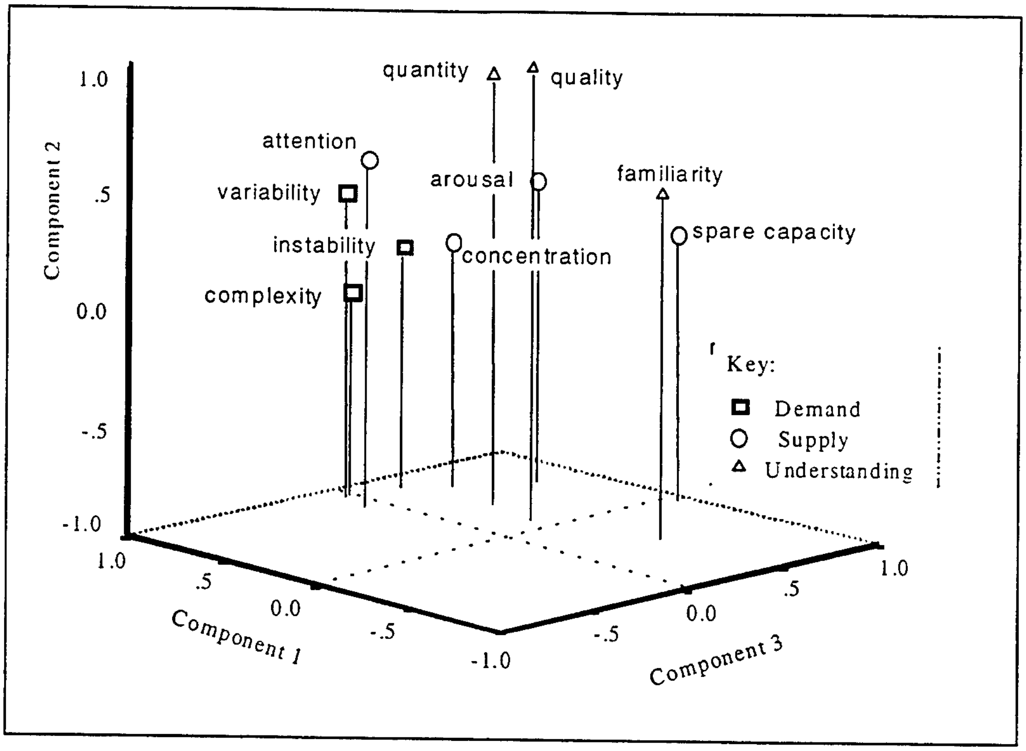

Figure 31. SART Factorial Component Plot in Rotated Space.

Figure 32 shows EDA box plots of the first factorial component for the treatments. The plots show the distributions to be fairly normal with closely equal variances. A univariate RM ANOVA test of within-subjects effects is significant by visual treatments (p < .011, F = 11.644, df = 1, error df = 7); however, the other treatments and interactions are not significantly different from each other.

The overall rating of SA is not significantly different across treatments according to a univariate RM ANOVA test of within-subjects effects. The overall SA rating is the difference between the sum of the ratings for the supply and the demand domains added to those for the understanding. Figure 33 shows EDA box plots of the SA ratings for the treatments.

Although the changes in SA are insignificant, the demands on maintaining awareness are increased with the use of the HMD. The application of an NP Friedman ANOVA test by ranks to the sum of the demand domain ratings shows significant differences across treatments (chi-square statistic = 15.968, df = 7, p < .025). A Scheffé pair-wise comparison test for the contrast of rank means shows that this difference is attributable to the visual treatments. Figure 34 shows box plots for the demand sum and Figures H-1 through H-3 show plots for the demand dimensions. The plots are not as uniform, with large differences in variances and several outliers. Considering the separate dimensions, the ratings show significant increases in instability (chi-square statistic = 19.936, df = 7, $p < 0.006$) and complexity (chi-square statistic = 16.245, df = 7, $p = .023$) for the moving vehicle or with use of the HMD.

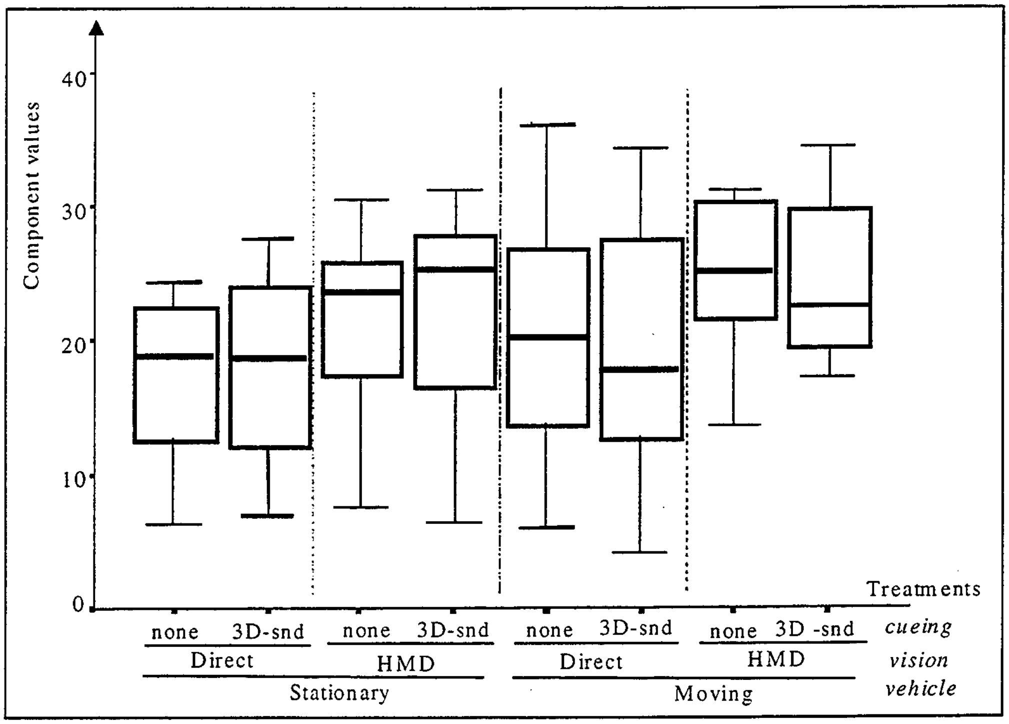

Figure 32. SART First Factorial Component Box Plots.

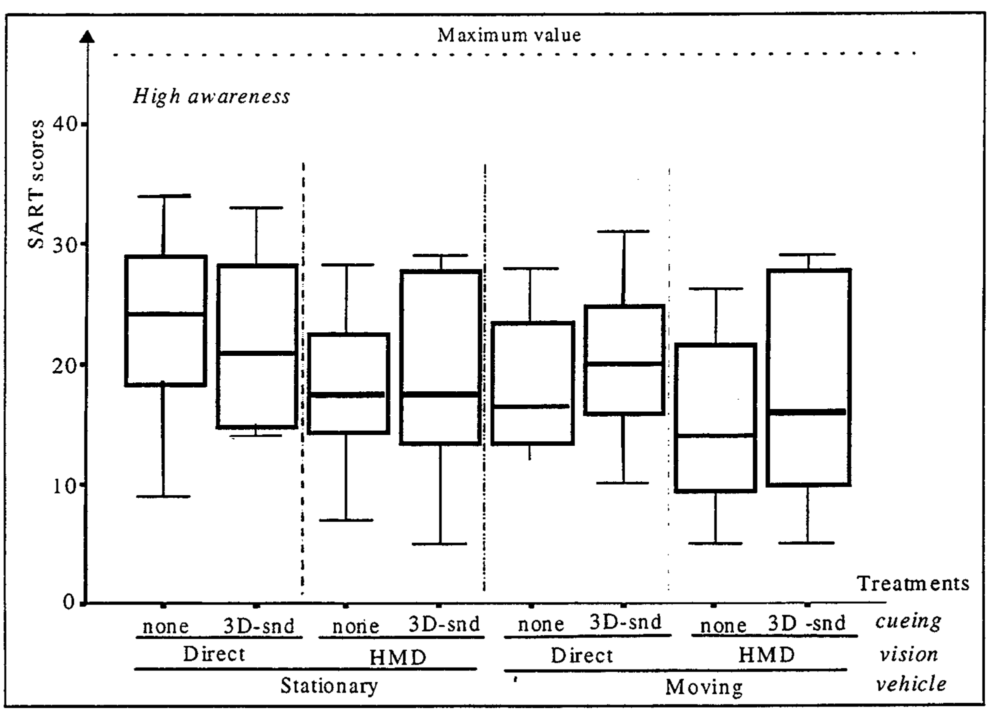

Figure 33. SART Situation Awareness Box Plots.

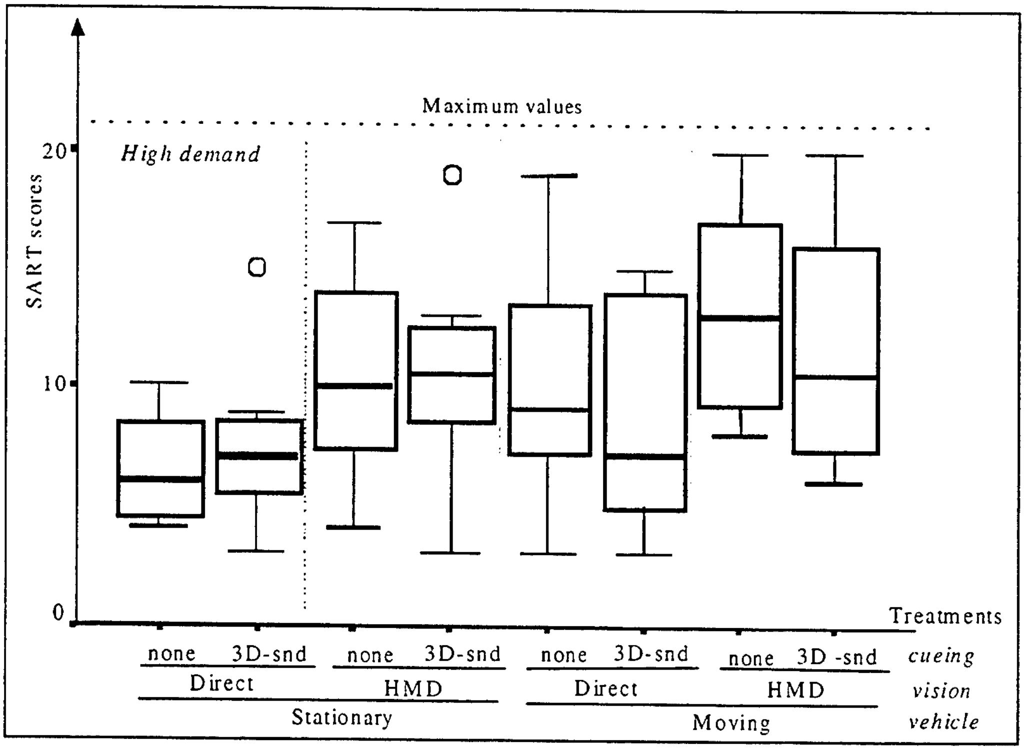

Figure 34. SART Demand Sum Box Plots.

Although situation understanding decreases with use of the HMD, there is an increase in supply of awareness. The sum of the understanding domain ratings is statistically significant across treatments (chi-square statistic = 15.728, df = 7, $p < .028$), while the supply domain sum is closely significant (chi-square statistic = 14.612, df = 7, $p < .041$). Figure 35 shows box plots for the supply sum, and Figures H-4 through H-7 show plots for the supply dimensions. Similarly, Figure 36 shows plots for the understanding sum, and Figures H-8 through H-10 show plots for the understanding dimensions. Several of the plots for the supply and understanding are skewed from normality or bound by the maximum value. Considering the separate dimensions of the questionnaire, the ratings show significantly less familiarity (chi-square statistic = 25.155, df = 7, $p < 0.001$) for the moving vehicle or with use of the HMD. Further, more concentration (chi-square statistic = 17.244, df = 7, $p < 0.016$) was needed for the HMD than direct vision.

In general, the plots for the questionnaire dimensions show the detrimental effects on SA of the use of the HMD as compared to direct vision. Considering the awareness demand, there is an increasing trend in variability along with the statistically significant increases in instability and complexity. Again, for awareness supply, there are increasing trends in arousal and divided attention and a decrease in spare mental capacity, along with the significantly increased need for concentration. Finally, considering situational understanding, there are decreasing trends in information quality and quantity along with the significant decrease in familiarity.

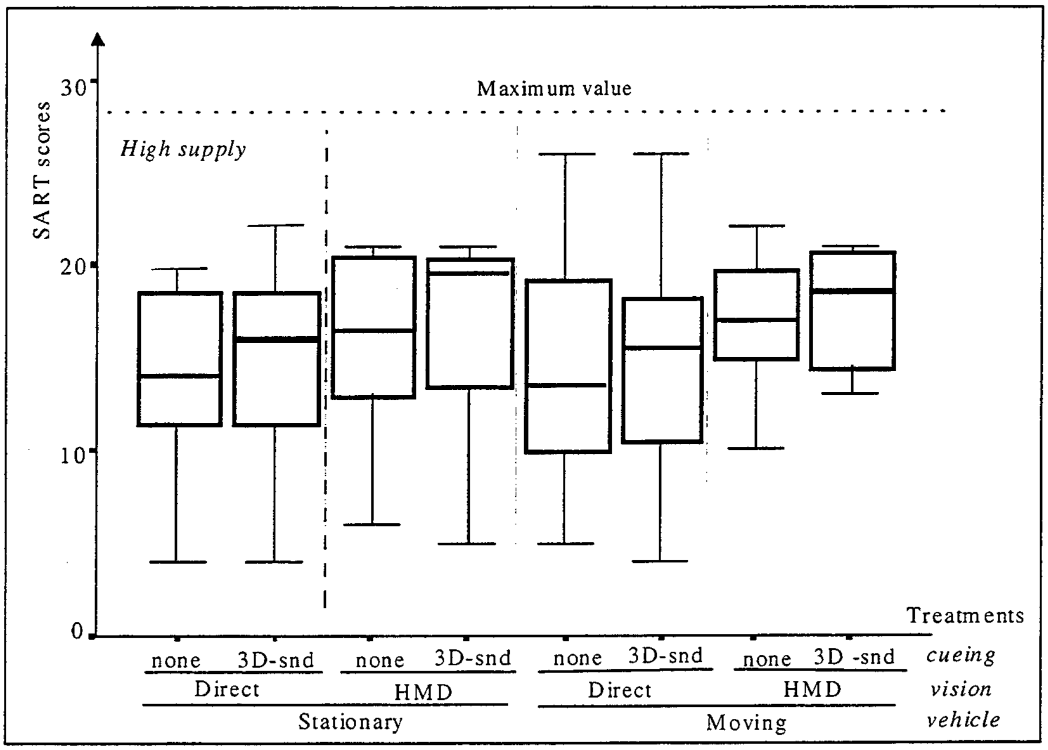

Figure 35. SART Supply Sum Box Plots.

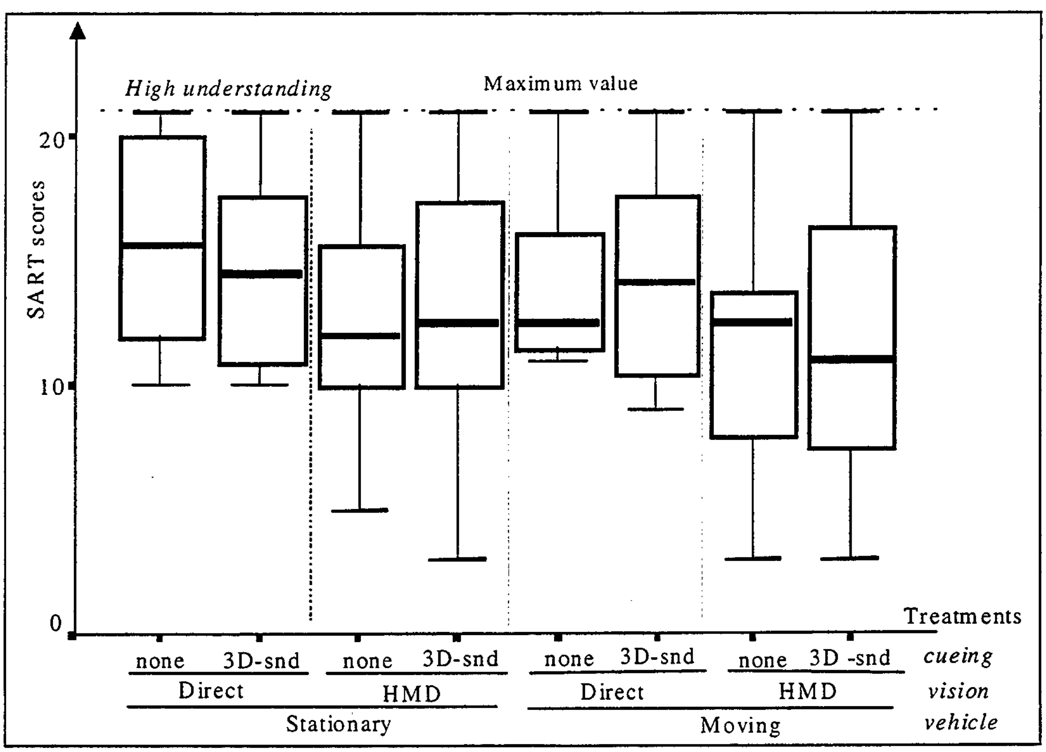

Figure 36. SART Understanding Sum Box Plots.

4.4 Usability Evaluations

The participants rated the four display configurations (direct viewing or HMD, with or without audio cueing) as to their usability in the vehicle mobility modes (stationary or moving). They rated direct viewing as more useful than the HMD and the sound localization as being of more use with the HMD than with direct viewing. A univariate RM ANOVA shows significant effects (F = 103.176, dfn = 1, dfd = 6, $p < .001$) for the vision mode ($p < .001$) and the interaction of the vision mode with the cueing format ($p < .046$). Figure 37 is a plot of the average ratings as a function of the treatment conditions. One participant who had completed the experiment did not have time to perform the ratings because of a previous travel arrangement.

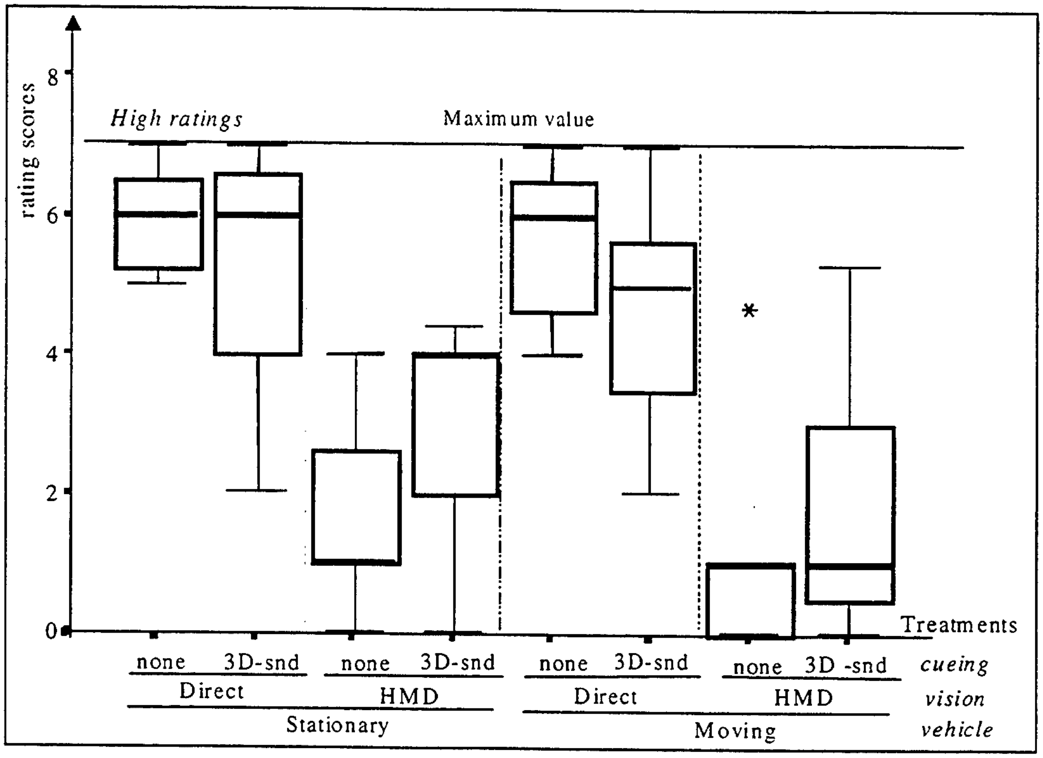

Figure 37. Exit Rating Box Plots.

4.5 Family-wise Significance

The statistically significant analyses are rank ordered by the (two-sided) probabilities of significance in Table 8, along with the corresponding overall alpha level computed by the Holm procedure. The table shows that family-wise significant differences result among the treatments for the analyses of the task performance, allocations of attention for detection and identification, TLX workload, SART SA, motion sickness, and the usability evaluation. The analysis for the heart rate is not significant at the 0.05 family-wise level.

Table 8. Summary of the Statistically Significant Results

Task	Component	Probability	Holm α Levels
1. Driving performance			
	Overall	0.0001	0.0056
	time to detect	0.0001	0.0100
	Number detected	0.001	0.0125
	time to identify	0.001	0.0167
	number identified	0.001	0.0250
	number identified correctly	0.001	0.0500
2. Motion sickness-			
	First factorial component	0.000	0.0062
	total severity	0.000	0.0125
	nausea symptom	0.000	0.0167
	general discomfort	0.000	0.0083
	nausea	0.000	0.0100
	stomach awareness	0.000	0.0125
	sweating	0.009	0.0167
	oculomotor symptom	0.000	0.0250
	disorientation symptom	0.004	0.0500
	dizziness (eyes open)	0.003	0.0125
	dizziness (eyes closed)	0.003	0.0167
3. Usability evaluation		0.000	0.0071
4. Attention allocation loading for identification-			
	Second factorial component	0.001	0.0083
	auditory	0.001	0.0125
5. TLX workload-			
	First factorial component	0.001	0.0100
	overall sum	0.000	0.0167
	demand sum	0.001	0.0250
	mental	0.001	0.0167
	physical	0.010	0.0250
	temporal	0.010	0.0500
	interaction sum	0.001	0.0500
	effort	0.001	0.0167
	performance	0.001	0.0250
	frustration	0.001	0.0500
6. Attention allocation loading for detection-			
	First factorial component	0.009	0.0125
	auditory	0.001	0.0125
	psychomotor	0.001	0.0167
7. SART-			
	First factorial component -	0.011	0.0167

For the significant analyses, the table lists the statistical results for separate analyses of the component measures using the Holm procedure to control the (sub) family-wise 0.05 alpha level. For the task performance, the analyses for the detection and identification times and numbers are family-wise significant. The allocation of attention for the detection task is significant because of the loading on the auditory and psychomotor channels. Similarly, the attention allocation for the identification task is significant because of the loading on the auditory channel. For the TLX workload, the analyses of the grand, demand and interaction sums are significant, as are those of all components for the sums. Although the SART analysis of the factorial component is significant, those for SA and the SA demand, supply, and understanding are not. The total severity and the nausea, oculomotor, and disorientation symptoms of the motion sickness are family-wise significant, as are the components listed for the symptoms.

Referring to the previous text, the performance for the overall task, the detection task, and the identification task are significantly influenced by the vehicle motion and the vision treatments. The time to detect is also influenced by the three-way Vehicle Motion x Vision Mode x Cueing Treatments interaction. Similarly, the questionnaires are statistically influenced by the vehicle motion and the vision treatments. In particular, the loading factor for attention allocation of the psychomotor channel for the detection task is influenced by the vision treatment, while the auditory channel of the detection and identification tasks are influenced by the cueing treatment. The NASA-TLX workload components are influenced by the vision treatments. The general discomfort component of motion sickness is induced by the vehicle motion with the HMD. Further, the usability evaluation is influenced by the vision treatment and the interaction with the cueing treatments. Finally, although family-wise insignificant, the demand components of instability and complexity and the concentration supply component for SA are influenced by the vehicle motion and the vision treatments, while the understanding component of familiarity is influenced by the vision treatment.

5. Discussion

In this section, the effects of the vision systems, localized auditory cueing, vehicle motion, and environment on task performance and mental workload are summarized. Task performance is reviewed. Next, mental workload as measured by attention allocation, perceived workload and SA, and motion sickness, is discussed. The long-term impact of mental workload on performance is briefly reviewed. Finally, the comments by the participants are discussed.

5.1 Treatment Effects on Performance and Mental Workload

The effects of the vision system, sound localization, vehicle motion and task environment on the performance and mental workload are reviewed.

5.1.1 Vision System

The limited FOV and resolution of the indirect vision system increased the visual workload by decreasing the target visibility and the search glimpse size. The reduced glimpse size increased the number of glimpses needed for search and the cognitive workload needed to maintain a useful search pattern over the sector. The visual performance was limited by the resolution and FOV of the HMD used in this study. The target visibility is modulated by the optical properties of the indirect visual system, which are restricted by the FOV of the HMD. At 30 degrees, the FOV of the HMD is 61% of the 48.8-degree FOV of the camera, and the scene on the HMD appears expanded 1.63 times that of the real world, making the targets 0.61 times smaller in linear size. Further, the HMD with 180,000 rasters has 68.8% the angular resolution of the camera (768 x 494 rasters). For these reasons, the targets on the HMD appear 0.42 smaller in linear size than they would with an HMD optically matched to the camera. The electronic camera has auto-focusing with automatic white balance and brightness control maintained by an auto-iris.

5.1.2 Sound Localization

Sound localization with the intermittent tones increased cognitive workload by interrupting the visual search to allow focusing on the following chirp. In this way, the acoustic aiding, which was meant to be integrated with the visual stimulus, instead became a secondary task competing for attentional resources. Although this was irritating with the large FOV of direct viewing requiring only a few search glimpses, the time taken to evaluate tones was less than that needed for the multiple glimpses used with the indirect vision system. The field of search was limited to the right front 60-degree sector for safety reasons. Certainly, sound localization has proved to be useful in target search with an HMD over a 110-degree front (Nelson et al., 1998). We would expect that sound localization would be helpful during direct viewing with a wider field of search such as along a full 180-degree front.

The effectiveness of the sound localization was further limited by the relative insensitivity of humans to synthetically generated stereophonic sounds through earphones. The literature (Begault & Wenzel, 1990) about synthetic sounds generated in earphones reports that humans have a roughly 20-degree localization accuracy in both azimuth and elevation. The localization is reported to be more accurate at a 30- to 60-degree angle to the side of the head. Furthermore, the HRTF used in the Air Force 3-D sound localization system is a fixed database measured from a manikin standard. However, the HRTF of an individual is determined by the time delay and amplitude differences in the receipt of the same signal at the two ears, which can vary with head size and the fine structure of the pinna of the outer ear.

5.1.3 Vehicle Motion

Vehicle motion further decreased the resolution because of image blurring; however, for some participants, motion stereopsis of the target against the variable background increased target visibility. Vehicle motion dynamically changed the image scene, making it appear unstable and increasing the cognitive workload. More concentration was needed to maintain a mental model of the relation of the viewer to the SASPRF. The mental model is needed to maintain a useful search pattern; this is especially true with the limited FOV of the HMD. Further, there was an increased chance of losing the detected target during identification. Cognitive workload was increased during vehicle motion with the HMD that tended to induce motion sickness. This forced a monitoring of discomfort awareness as a secondary task competing for attentional resources. In some cases, motion sickness dominated the responses, causing the participant to momentarily discontinue the primary task of target detection and identification; however, none of the participants elected to stop trial runs.

Motion sickness is reported (Yardley, 1992) to be provoked by sensory conflict between the visual field and sensorimotor activities, which involve the vestibular system through body and head movements. Since the participants sat on the right side of the vehicle and the camera was mounted in the center, the movements seen on the HMD were different from those that were received physically from the seat through the vehicle frame. The inconsistency between the visual and physical stimuli may have been disconcerting to some, especially while the camera was rotated off to the side during search and when the vehicle backed during the return drive to the starting line. This problem may have been aggravated further by latencies in the responses of the pan-and-tilt mechanism that resulted in the camera lagging slightly behind the head movements.

Another source of motion sickness is motion blurring of the image on the LCDs during side view searches from the moving vehicle. This results in the display appearing slightly out of focus because the video return is blurred, with an accompanying loss of dynamic resolution. In some, this apparently induces a lack of convergence accommodation, resulting in blur-driven asthenopia symptoms. As reported in the literature, motion sickness, especially asthenopia symptoms (Ebenholtz, 1992), can be produced by insufficiencies in visual stimulation.

5.1.4 Task Environment

The task environment for indirect vision tended to increase sensitivity to motion sickness because of sensory degradation while participants rode in the enclosed compartment. Although the direct vision target search was performed with unrestricted natural vision from an open cab, the indirect vision search was from an enclosed cab. The participants experienced physical isolation, darkness, heat, and noise during the trial runs with the indirect vision system, which were different from conditions for direct vision.

5.2 Task Performance

The target detection and identification performances are of interest. The probabilities for target detection and identification and associated average times are plotted in Figures 38 through 42 as a function of the treatments. Table 9 lists the values for these plots. The figures show that the use of the HMD decreases the probability of detection and increases the detection time for those targets that are detected. Given detection, although the HMD and vehicle motion reduce the probability of identification and increase the identification time for targets that are identified, vehicle motion decreases the probability of correct identification. Figure 38 is a plot of the probability of target detection. Figure 39 is a plot of the average target detection times, given a successful detection. Figure 40 is a plot of the conditional probability of target identification, given detection. Figure 41 is a plot of the average target identification times, given identification. Finally, Figure 42 is a plot of the conditional probability that the identification is correct.

Table 9. Statistically Significant Task Performance

	Time (seconds)		Targets (percent)		
Configuration	Detect	Identify	Detect	Identify	Correct
1. ***Stationary***					
1.1 *Direct viewing*					
1.1.1 No sound	3.367	4.39	90.10	94.79	87.20
1.1.2 Sound	4.042	4.39	90.10	94.79	87.20
1.2 *HMD viewing*					
1.2.1 No sound	8.067	5.62	55.73	42.99	73.91
1.2.2 Sound	8.283	5.62	55.73	42.99	73.91
2. ***Moving***					
2.1 *Direct viewing*					
2.1.1 No sound	4.704	6.46	88.02	85.21	52.78
2.1.2 Sound	4.041	6.46	88.02	85.21	52.78
2.2 *HMD viewing*					
2.2.1 No sound	7.732	7.01	30.72	30.51	61.11
2.2.2 Sound	9.054	7.01	30.72	30.51	61.11
Maximum possible	15.0	10.0	96	No. detected	No. identified

Notes on statistical significance:

Time to detect	-	movement, vision, and movement by vision by cueing.
Targets detected	-	movement, vision, movement by vision.
Time to identify	-	movement, vision, movement by vision.
Targets identified	-	movement, vision, movement by vision.
Correct identification	-	movement, vision

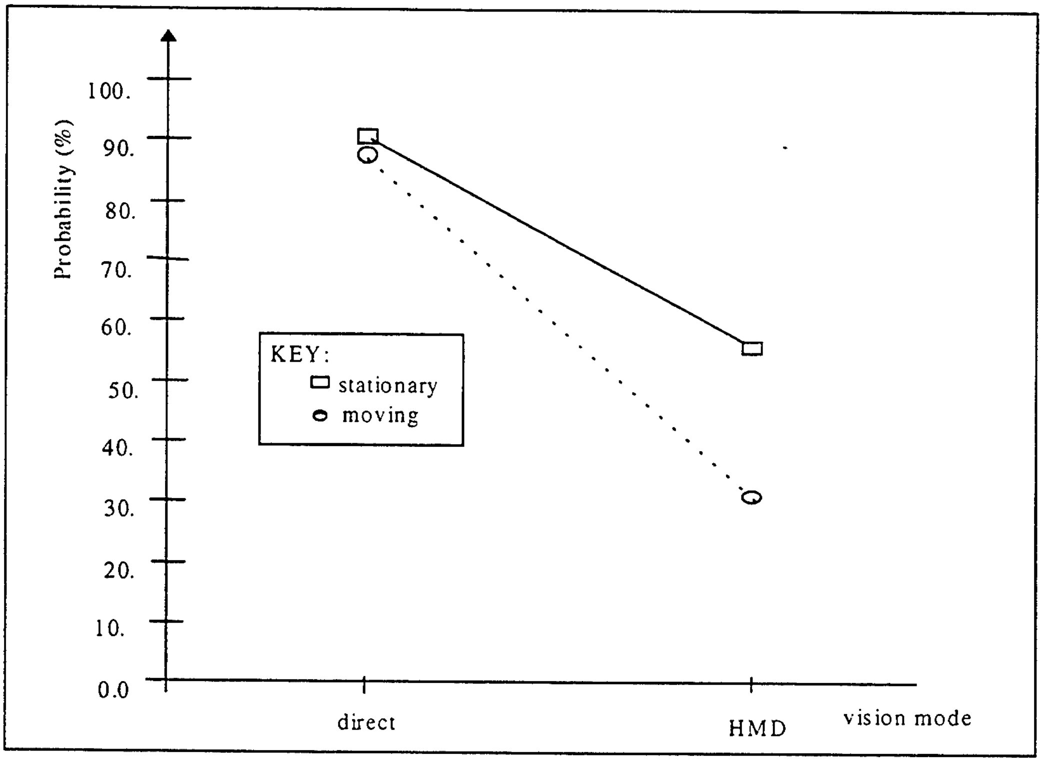

Figure 38. Probability of Target Detection.

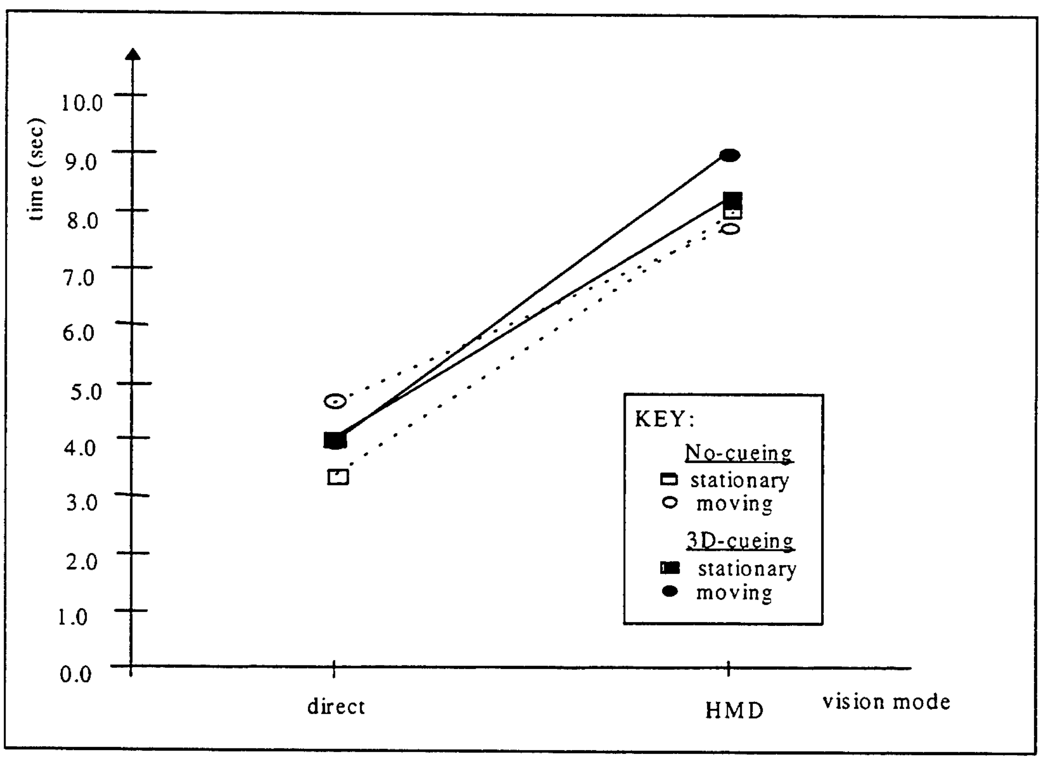

Figure 39. Average Target Detection Time (given success).

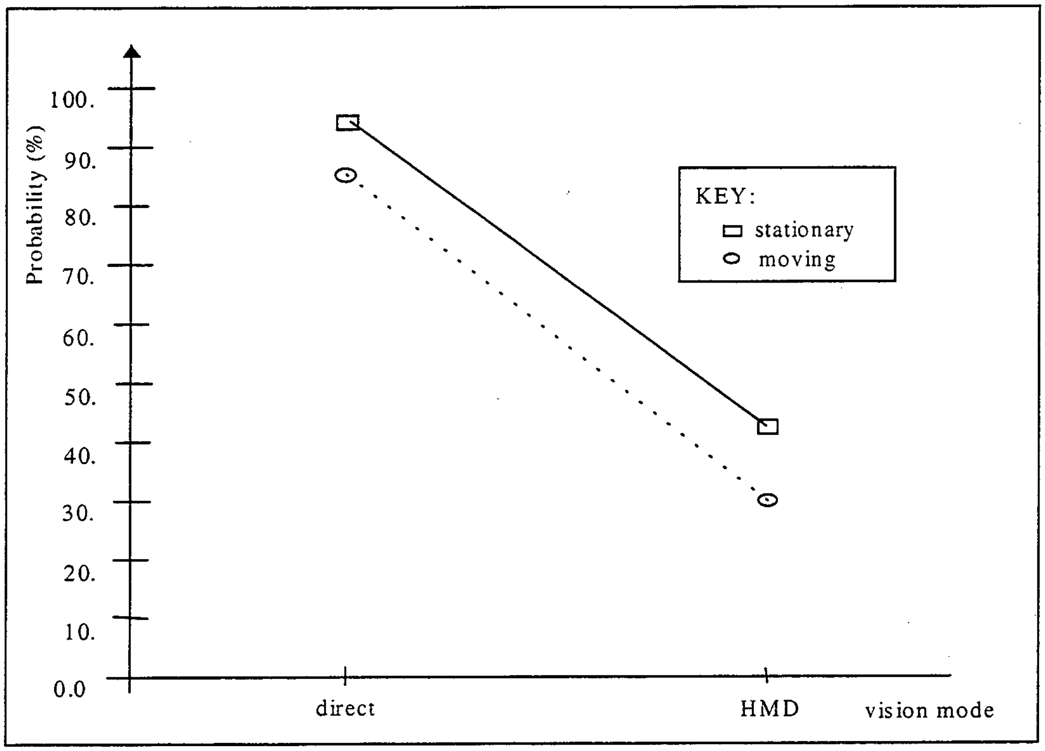

Figure 40. Conditional Probability of Target Identification (given detection).

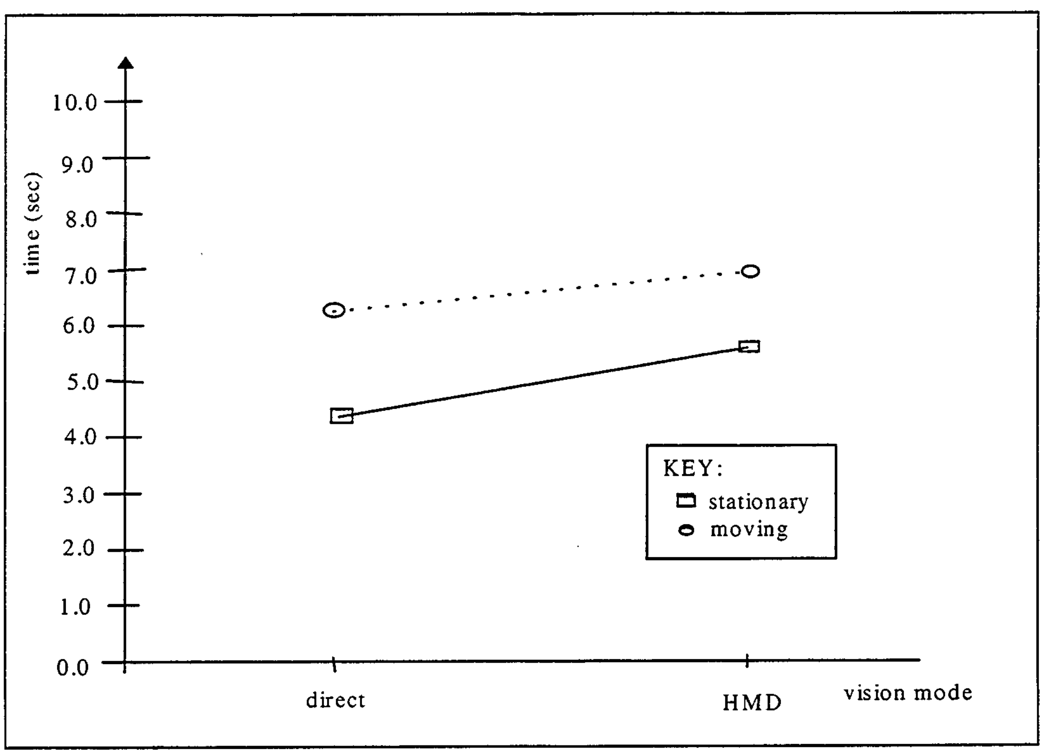

Figure 41. Average Target Identification Time (given success).

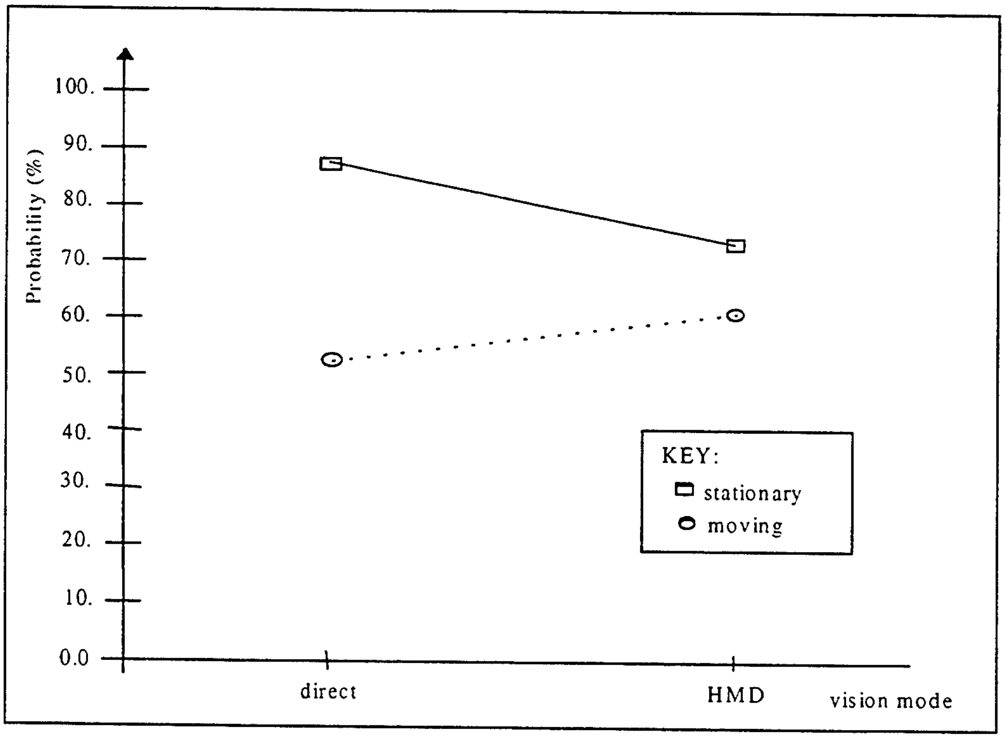

Figure 42. Conditional Probability That Identification is Correct.

5.3 Mental Workload

The mental workload is of interest since it can influence performance. Summarized are the mental workload measures as determined by the attention allocation, the perceived task workload, SA, and motion sickness.

5.3.1 Measures

Table 10 lists the average scores for the statistically significant mental workload measures as a function of the pertinent treatments. The maximum possible scores are listed for reference. Table 11 lists the average scores for the statistically significant attention allocation factors for the detection and identification tasks. The equivalent verbal anchors are listed, along with the scores for reference. Note that the maximum possible score on an attention allocation channel is 7.

5.3.2 Workload Costs

Over long periods of time, excessive mental loading can lead to fatigue and consequently slow responses and increase errors. Furthermore, increased mental workload can result in a loss of SA for other problems in the environment, which can impact future decision making. The increased workload, the demand on SA, and the chance of motion sickness increase the psychological stress on the gunner with the indirect vision system. In a two-person vehicle, the gunner may be expected to perform other functions such as navigation and communications. At high stress levels, the resulting physiological arousal is detrimental to performance.

Table 10. Statistically Significant Mental Workload Questionnaire Results

Configuration	Motion Sickness[a]	TLX Workload	SART Factorial
1. *Stationary*			
1.1 Direct viewing	4.41	13.96	18.82
1.2 HMD viewing	4.41	28.10	23.28
2. *Moving*			
2.1 Direct viewing	4.41	13.96	18.82
2.2 HMD viewing	22.19	28.10	23.28
Maximum possible	120	54	N/A

[a]Note: No trials aborted because of motion sickness.
Notes on statistical significance:
Motion sickness - movement by vision (HMD with motion)
TLX workload - vision
SART factorial - vision

Table 11. Statistically Significant Attention Loading Factors

Configuration	Value[a]	Verbal Anchor
I. DETECTION TASK		
(a) Visual channel:		
All treatments	3.575	"discriminate"
(b) Cognitive channel:		
All treatments	3.367	"recognize"
(c) Audio channel:		
Non cueing treatments	0.062	"none"
Sound cueing treatments	3.293	"orient," "verify"
(d) Psychomotor channel:		
Direct vision	1.788	"toggle"
HMD vision	3.781	"continuous," "manipulate"
II. IDENTIFICATION TASK		
(a) Visual channel:		
All treatments	3.973	"inspect"
(b) Cognitive channel:		
All treatments	3.667	"recognize"
(c) Audio channel:		
Non cueing treatments	0.000	"none"
Sound cueing treatments	2.725	"orient," "verify"
(d) Psychomotor channel:		
All treatments	3.039	"continuous"

[a]Note: maximum possible on any channel equals 7.

The immediate effect is to produce tunneling or narrowing of the perceptual and cognitive attention to concentrate on the detection and identification tasks while ignoring the surroundings. There is a tendency for working memory loss with reduced capacity for processing new or complex material, along with a focus on well-learned responses and a rapid execution of these responses at the expense of possible errors. The resultant shedding of secondary tasks may not be done in an optimal order for successfully coping with the problem environment. In particular, motion sickness distracts from the task since the discomfort is intrusive and the gunner cannot readily concentrate. Although the immediate task performance may deteriorate, the long-term effects are cumulative, resulting in accumulated fatigue over time, which can adversely affect performance of subsequent tasks (Wickens, Gordon, & Liu, 1998).

5.4 Participants' Comments

The comments by the participants agree with the experimental results. The comments are listed in Table 12. The participants felt that although sound localization worked moderately well, the sound increased the detection times for direct viewing from the stationary vehicle. In this treatment, they primarily relied on sight by scanning with their eyes and not turning their heads. However, the sound helped orient the participants toward the target with the HMD in the stationary vehicle. Furthermore, the participants reported that sound localization helped them to find the targets from the moving vehicle with both direct vision and the HMD.

6. Conclusions

The choice of HMD that was used in this study with its reduced resolution and limited FOV severely limited the detection and identification of targets. Fewer targets were detected and identified, and it took longer to do so with the HMD compared to targets processed with direct vision. Using the HMD in a moving vehicle further reduced task performance. Sound localization with intermittent tones increased the time to detect for direct viewing in a stationary position but decreased the time for the HMD in a moving vehicle. Similar comments apply to identification from the stationary position; however, fewer targets were identified from the moving vehicle with sound localization than without. The advantages of auditory cueing for target detection may have been limited by the choice of an intermittent tone for sound localization and the restricted search sector used in the experiment.

Ratings of task attention loading show that increased attention was needed for the detection task with audio cueing, especially with the HMD. This is also true for the identification task. The use of the HMD increased the perceived workload because of the limited FOV. For SA, use of the HMD with vehicle motion made the perceived situation more unstable and complex, decreased familiarity, and concurrently increased the need to concentrate on the task. Finally, the use of the HMD with vehicle motion tended to induce general discomfort, which led to motion sickness that, in turn, increased mental workload. Over a long period of time, the increase in workload may lead to fatigue and errors.

Table 12. Comments by Participants

Stationary vehicle

(a) Direct viewing –

<u>No sound cues</u>

Easy to observe targets.
Does not cause stress.
Less distracting.

<u>3D-sound cues</u>

Increases detection times.
Still primarily relying on sight.
Sound works moderately well; minimal benefit.
Scan with eyes and do not turn head.

(b) HMD –

<u>No sound cues</u>

Hard to observe targets; camera is jerky.
Camera is not clear and makes your eyes strain.
Low resolution, motion sickness.

<u>3D-sound cues</u>

Sound helps orient you.
Hard to observe targets.
Need better camera; sound cues help.

Moving vehicle

(a) Direct viewing –

<u>No sound cues</u>

Easy to observe targets; would stop to identify.
Does not cause stress.

<u>3D-sound cues</u>

Sound helps orient; increases target detection.
Still primarily relying on sight.

(b) HMD –

<u>No sound cues</u>

Extremely hard to view targets.
Camera vibrates and jumps.

<u>3D-sound cues</u>

Sound helps orient.
Sound needs to be louder and adjustable.
Better fitting helmet and ear phone plugs.
Sound cues needed with zoom lens for both moving and stationary.

---

7. Recommendations for Further Research

We recommend continuing studies of the performance with HMDs, since the development of miniaturized camera systems, high performance computers, and low cost, high resolution HMDs with a wide FOV will in the future provide a more natural "virtual reality" display environment for the operator of ground military vehicles.

We recommend investigating the advantages of combined visual and sound localization cues for target detection with HMDs. Although the audio cue will orient the gunner, the visual cue can find the target within the visual field with the accuracy of the target database.

The use of subjective questionnaires to measure perceived workload, SA, and motion sickness has provided insight into the increases in mental workload incurred with indirect vision targeting. We recommend the collection of subjective data in further experiments and the use of factorial analysis in data analysis of questionnaires to control Type I error.

Motion sickness continues to be a concern for indirect vision operations, and techniques for controlling sickness without adversely affecting performance should be researched further.

We recommend further investigations into modeling task performance and the effects of mental workload on indirect vision operations. A point of particular concern is the inclusion of motion sickness, including the sources and symptoms and their effect of performance.

Since future vehicle designs will include multitasking along with targeting, we recommend research into multiple task performance involving crew interaction and communications and navigation functions for indirect vision activities. The present study was limited to targeting and did not consider the higher cognitive functions that are required of future combat vehicle operators. A future study should include automated adaptive aiding for the performance of multiple tasks in future combat systems.

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APPENDIX A

FORMS FOR INFORMED CONSENT AND QUESTIONNAIRES

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Table A-1. Informed Consent Form

Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD

Title of Research Project: Comparison of direct vision to a head-mounted display, with and without audio cueing, for target detection and identification from a stationary and a moving vehicle.

Principal Investigator: Christopher Smyth   Phone: (410) 278-5935
SSCB, SPD, HRED, ARL
Aberdeen Proving Ground, MD 21005-5425

Location of Study: SASPRF
Aberdeen Proving Ground, MD

Purpose of Study

You are invited to participate in a target detection study that compares direct to indirect vision. In both conditions, you will search for targets, but in the indirect vision condition, you will view the SASPRF through a helmet-mounted video display that is receiving an image from a head-slaved video camera. The camera is mounted on the roof of a HMMWV. This work is being conducted to determine the problems that may occur when vehicles are operated indirectly from externally mounted cameras. The U.S. Army is interested in this information because it plans to develop armored vehicles that can be driven and operated with indirect vision systems so that the crew members will be better protected from enemy fire.

Procedure

If you decide to participate in our study, one of our administrators will describe the details of the procedure to you. A brief description is as follows: You will be sitting in a HMMWV that will either be parked on a target facility or driven down the center. For the indirect search, you will be wearing a helmet with a head-mounted display that will show you the scene as you turn your head. You will be asked to tell the experimenter when you see a target. For part of the study, you will hear a stereo tone that will point you in the direction of the target. You will then use a pair of binoculars or the camera in zoom to identify the target. The study will take about 6 hours with an hour break for lunch. There will be a 10-minute rest break between the phases. You will be given a questionnaire to answer following the indirect search. The questionnaire will ask for your impressions of the visual display and its performance.

Risks

There are minimal risks associated with this experiment. The experiment is being conducted on the SASPRF. No weapon firing will be allowed during this study. However, for your own safety you should obey the safety officer, who will remain next to you throughout the study.

A potential risk concerns motion sickness which can occur in some people while riding in enclosed compartments. Symptoms of motion sickness are nausea, cold sweating, pallor, and vomiting. You can stop the experiment at any time by telling the safety officer, and if you feel sick, we would prefer that you stop the experiment. Motion sickness bags will also be positioned near your seat. If you vomit, the safety officer will stop the experiment. Also, if you feel or become sick, you will be held at the site for at least 1 hour until your symptoms subside.

For your own safety, you should wear your safety belt whenever the HMMWV is moving. In addition, you will receive an orientation and safety briefing before you actually begin the experiment.

Table A-2. Estimating Attention Allocation Loading Factors Questionnaire for Detection and Identification Tasks

Subject: Date: Time:

Condition:

Please check all workload elements performed during this test condition.

```
                                           discriminate      track
Visual-     none     detect                       inspect  locate      read     scan
            |----------|----------|----------|------x---|----------|---x-----x|----------|
            0          1          2          3          4          5          6          7
```

```
                   selection                  recognize                       evaluate
Cognitive-    none      auto                                        judge  recall      estimate
              |----------|-x--------|----------|-------x--|------x---|--x-------|-------x--|
              0          1          2          3          4          5          6          7
```

```
                                                              verify          discriminate
Auditory-     none      detect     orient                          focus  speech       interpret
              |----------|----------|----------|----------|--x------x|----------|------x---|
              0          1          2          3          4          5          6          7
```

```
                                    continuous                                writing
Psychomotor-  none      speech     toggle                  manipulate     adjust     typing
              |----------|----------|-x----x---|----------|------x---|--------x-|----x-----|
              0          1          2          3          4          5          6          7
```

Estimating Workload Scales
For allocating attention loading factors

1. Visual Loading-

Scale Value *Descriptor*
- 0.0 No Visual Activity
- 1.0 Visual Register/Detect (detect occurrence of image)
- 3.7 Visual Discriminate (detect visual differences)
- 4.0 Visual Inspect/Check (discrete inspection/static condition)
- 5.0 Visual Locate/Align (selection orientation)
- 5.4 Visually Track/Follow (maintain orientation)
- 5.9 Visually Read (symbol)
- 7.0 Visually Scan/Search Monitor (continuous/serial inspection, multiple conditions)

2. Cognitive Loading-

Scale Value *Descriptor*
- 0.0 No Cognitive Activity
- 1.0 Automatic (simple association)
- 1.2 Alternative Selection
- 3.7 Sign/Signal Recognition
- 4.6 Evaluation/Judgment (consider single aspect)
- 5.3 Encoding/Decoding, Recall
- 6.8 Evaluation/Judgment (consider several aspects)
- 7.0 Estimation, Calculation, Conversion.

3. Auditory Loading-

Scale Value *Descriptor*
- 0.0 No Auditory Activity
- 1.0 Detect/register sound (detect occurrence of sound)
- 2.0 Orient to Sound (general orientation./attention)
- 4.2 Orient to Sound (selective orientation./attention)
- 4.3 Verify Auditory Feedback (detect occurrence of anticipated sound)
- 4.9 Interpret Semantic Content (speech)
- 6.6 Discriminate Sound Characteristics (detect auditory differences)
- 7.0 Interpret Sound Patterns (pulse rates, etc.)

4. Psychomotor Loading-

Scale Value *Descriptor*
- 0.0 No Psychomotor Activity
- 1.0 Speech
- 2.2 Discrete Actuation (button, toggle, trigger)
- 2.6 Continuous Adjustment (movement control, sensor control)
- 4.6 Manipulative
- 5.8 Discrete Adjustive (rotary, vertical thumbwheel, level position)
- 6.5 Symbolic Production (writing)
- 7.0 Serial Discrete Manipulation (keyboard entries)

Table A-3. NASA-TLX Workload Rating Form

Subject: Date: Time:

Test Condition:

Mental Demand: How much mental and perceptual activity was required (e.g. thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

low |----|----|----|----|----|----|----|----|----|----| high

Physical demand: 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?

low |----|----|----|----|----|----|----|----|----|----| high

Temporal demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

low |----|----|----|----|----|----|----|----|----|----| high

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

low |----|----|----|----|----|----|----|----|----|----| high

Performance: 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?

good |----|----|----|----|----|----|----|----|----|----| poor

Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

low |----|----|----|----|----|----|----|----|----|----| high

Table A-4. Estimating Motion Sickness Questionnaire

Subject: Date: Time:

Test Condition:

Please rate the following measures of motion sickness:

General Discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eyestrain	None	Slight	Moderate	Severe
Difficulty Focusing	None	Slight	Moderate	Severe
Increased Salivation	None	Slight	Moderate	Severe
Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty Concentrating	None	Slight	Moderate	Severe
Fullness of Head	None	Slight	Moderate	Severe
Blurred Vision	None	Slight	Moderate	Severe
Dizzy (eyes open)	None	Slight	Moderate	Severe
Dizzy (eyes closed)	None	Slight	Moderate	Severe
Vertigo *	None	Slight	Moderate	Severe
Stomach Awareness **	None	Slight	Moderate	Severe
Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Table A-5. Situation Awareness Rating Questionnaire

Subject: Date: Time:

Test Condition:

Please rate the following measures of situation awareness:

DEMAND			
Instability of situation:	low	1--------2--------3--------4--------5--------6--------7	high
Variability of situation:	low	1--------2--------3--------4--------5--------6--------7	high
Complexity of situation:	low	1--------2--------3--------4--------5--------6--------7	high
SUPPLY			
Arousal:	low	1--------2--------3--------4--------5--------6--------7	high
Spare Mental Capacity:	low	1--------2--------3--------4--------5--------6--------7	high
Concentration:	low	1--------2--------3--------4--------5--------6--------7	high
Division of attention:	low	1--------2--------3--------4--------5--------6--------7	high
UNDERSTANDING			
Information Quantity:	low	1--------2--------3--------4--------5--------6--------7	high
Information Quality:	low	1--------2--------3--------4--------5--------6--------7	high
Familiarity:	low	1--------2--------3--------4--------5--------6--------7	high

Table A-6. Usability Rating Questionnaire

Usability Rating

Subject: Date: Time:

Please rate the four target detection and identification systems as to their usability for the military and write a brief rational for your choice. Remember that you are comparing the four systems to each other under the two conditions of vehicle stationary and moving. Please use this opportunity to make recommendations for improvements in the designs:

I. Stationary Vehicle:

Direct Visual w/ binoculars & no sound — not use |---------|---------|---------|---------|---------|---------|---------| would use
0 1 2 3 4 5 6 7

Reason:

Direct Visual w/ binoculars & sound cues — not use |---------|---------|---------|---------|---------|---------|---------| would use
0 1 2 3 4 5 6 7

Reason:

HMD & camera w/ Zoom & no sound — not use |---------|---------|---------|---------|---------|---------|---------| would use
0 1 2 3 4 5 6 7

Reason:

HMD & camera w/ Zoom & sound cues — not use |---------|---------|---------|---------|---------|---------|---------| would use
0 1 2 3 4 5 6 7

Reason:

II. Moving Vehicle:

Direct Visual not use would use
w/ binoculars |---------|---------|---------|---------|---------|---------|---------|
& no sound 0 1 2 3 4 5 6 7

Reason:

Direct Visual not use would use
w/ binoculars |---------|---------|---------|---------|---------|---------|---------|
& sound cues 0 1 2 3 4 5 6 7

Reason:

HMD & camera not use would use
w/ Zoom |---------|---------|---------|---------|---------|---------|---------|
& no sound 0 1 2 3 4 5 6 7

Reason:

HMD & camera not use would use
w/ Zoom |---------|---------|---------|---------|---------|---------|---------|
& sound cues 0 1 2 3 4 5 6 7

Reason:

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APPENDIX B

PRELIMINARY STUDY: TARGET DISTANCE

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PRELIMINARY STUDY: TARGET DISTANCE

The preliminary portion of the study determined the detection probabilities for the two vision modes in a stationary position. These data were needed to design the site for the mobility studies. The participant was seated inside the vehicle parked at the firing line centered on a lane of targets, facing down range. The participant was asked to detect a target when it was presented within his FOV; he did not rotate his head from the viewing direction. The participant started each trial facing down range with his eyes closed and his head down before the target was displayed. The experimenter then activated a target with a toggle switch and a brief tone to alert the participant. The participant looked down range and activated a switch if a target was present, and if so, verbally estimated the distance. The participant had 10 seconds to respond, followed by 5 seconds' preparation for the next trial. Each target was presented at a distance from 25 meters to 400 meters from the observation point in 25-meter intervals to 100 meters, 50-meter intervals to 300 meters, and 100 meters to 400. In one of four trials, no target was presented to ascertain the participant's natural false alarm rate.

The investigation was conducted in three sessions with the participant evaluated in the first session with direct vision and then in the second session with the indirect HMD vision system. This was followed by another direct vision session to confirm training stability in a standard baseline, intrusion, return-to-baseline format. All sessions included three training trials followed by 37 experimental trials, including 10 with no targets. The target sequence including no-target events were random; in this way, the participant saw each of the nine settings three times. The participant was allowed a 10-minute break between sessions.

The experimental design for the first phase is a fixed factorial 3x9 experiment with repeated measures on the vision mode and target distance and subjects as a random factor. The experimental hypothesis is that the targets will be detected at greater distances with natural vision because of the increased visual acuity than with the HMD. The independent variables are (1) the vision modes and (2) the target distance. The dependent variables are the number of targets detected and the times to detect, if detected. The experimental results of this investigation are used to compute descriptive statistics for the detection distances as a function of distance for the two vision modes. The baseline and return-to-baseline direct vision data are compared to confirm training stability. A 10-second time limit was assigned to targets not detected.

The total detection times were analyzed in a 3x9 factorial repeated measures, parametric ANOVA as a function of target distance and vision mode. To approximate normal frequency distributions, the times were transformed with the natural logarithm before the statistical analysis. The computed F-values for the vision mode and distance main effects are statistically significant at the 0.001

level, and their interactions are statistically significant at the 0.01 level. This is true for the stringently critical F-distribution values (Winer, p. 864) that follow from the application of the Geisser-Greenhouse corrections to the degrees of freedom (Keppel, 1982, p. 470). The corrections are applied to account for any bias that may result from correlations between multiple measures obtained from the same subjects in a repeated measures experiment. For statistical convenience, maximal heterogeneity for the variances of differences is assumed. The within-treatment variances satisfy Cochran's test for homogeneity. The Cochran's test ratio (Winer, p. 208) computed as the ratio of the maximum cell variance to the sum of variances, is less than the critical test value (Winer, p. 876) at the 95% probability level. Of course, homogeneity of variances is a necessary condition for the unbiased application of a parametric test.

An application of the *post hoc* Scheffé's two-way comparison test shows that the mean detection times are not significantly different for the baseline and return-to-baseline direct vision tests. These results show that additional training did not occur during the intervention phase. However, the means for the indirect vision (HMD) intrusion are significantly larger then those for the direct vision at the 0.001 level. Furthermore, the mean times for the 150- to 400-meter set of ranges for the HMD are significantly larger than the mean times at the 0.001 level. The Scheffé test (Keppel, 1982, p. 151) allows multiple comparisons of means to be made without changes in the level of statistical significance.

The data for the false alarm rate of each subject, as determined from the number of non-targets falsely detected for the vision modes, are too sparse for statistical analysis. However, the false alarm rate was practically nil for the direct vision, while 4 of 8 subjects detected one or two false targets in ten possibilities in the indirect (HMD) mode. In all cases, the subjects recognized that the detection was false when the target did not drop after their button push, and they reported that fact to the experimenter.

The probability of detection and the mean target detection times are of interest for the baseline and intrusion phases as a function of distance. The standard deviation and confidence range are not computed for the 150- to 400-meter set of the indirect vision (HMD) mode, since missed targets occurred in that set. The statistics show agreement with the results of the Scheffé's two-way comparison tests. The data show that the baseline and return phase detection times are not significantly different, since the times for the return phase are within the 95% confidence band for the baseline times. This is true for all but the 400 meters in the return phase where the lower average for the return suggests a training effect at this distance. In contrast, while the mean times for the 25- to 100-meter set of the intrusion phase are within the baseline confidence band, those times for targets beyond 100 meters continue to increase above the upper boundary of the confidence band with increasing distance.

In summary, the analysis shows that there is practically no effect of the experimental order on the detection performance with direct vision. The average detection times for the return direct vision are within the 95% confidence intervals for the baseline to the 400-meter targets where there is an improvement because of training. Further, the analysis shows that the performance of the direct vision and indirect HMD are statistically the same to 100 meters. However, the performance of the systems diverges for distances beyond 100 meters, with the performance with the HMDs decreasing drastically with increasing distance because of the lower resolution.

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APPENDIX C

PRELIMINARY STUDY: TARGET BEARING

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PRELIMINARY STUDY: TARGET BEARING

The second phase of the preliminary portion determined the search times as a function of the angular offset for the two vision modes. The 24 targets used in this investigation were presented one at a time in a random order at a distance of 50 meters to 100 meters from the participant's position across a 170-degree visual front. These distances are within the 99% probability detection distance as determined from the data collected in the first phase. The targets are grouped for data analysis by four 45-degree sectors about the forward direction. The sectors are balanced in regard to target disposition, with each sector containing two targets each at the 50-, 75-, and 100-meter distances in a seemingly random pattern.

The participant was seated inside the vehicle parked at the center of the firing line facing down range. The participant was asked to find targets presented by searching with head movements across the visual front. The participant started each trial facing down range with his eyes closed and his head down before a target was displayed. He was told the direction to search ("right" or "left"); the target was then activated by the experimenter, and the participant began searching for the raised target. The participant pressed a button for automatic data recording and target depression when he had found the target and then verbally reported his estimate of the angular offset. The participant had 15 seconds to give his report, followed by 5 seconds' preparation for the next trial.

The investigation was conducted in three sessions with the participant evaluated in the first session with direct vision and then in the second session with the indirect vision system. The two sessions were followed by another direct vision session to confirm training stability. Each session block had 32 trials, with the 24 targets each presented once and no target presented in 8 trials to determine the false alarm rate. The target sequence was random for each block, and all distances and directions were equally likely; the no-target events were randomly distributed across this sequence. The participants were allowed a 10-minute break between session blocks.

The design for the second phase is a 3x24 fixed factorial experiment with repeated measures on the vision mode and the target and with subjects as a random factor. The target distance and bearing are random factors because of the random presentation order of the targets. The experimental hypothesis is that the targets will be detected sooner with natural vision because of the wider FOV than with the indirect vision HMD. The independent variables are (1) the vision modes and (2) the target set. The dependent variable is the time to detection.

The mean time to detect each target was plotted as a function of offset angle for the baseline and intrusion vision mode. The times were averaged across the eight subjects and include the 15-second time limit when a target was not detected. The regression trend analysis of the target detection data as a quadratic function of the angular offset was plotted for the baseline and intrusion modes. The analysis considered all target presentations, including those that were not seen within the 15-second time limit. Also, trend plots were plotted for just the detected targets; the target presentations that were not seen by the participants were not included in this analysis. A comparison of the two sets of plots suggests that the data fall within two groups, detected set and outliers.

The source of the outliers was deducted from the mean detection times and the probability of detection for each target as a function of vision mode. The data show that at least six targets had a low probability of detection during the intrusion mode. A check of the facility showed that these targets were to the sides against a dark brown woodland, unlike those to the front, which were seen against a brighter yellow-green field grass. Since the objective of this experiment is to determine the detection time as a function of offset angle for equally visible targets, the target presentations with time-limited measures are dropped from the analysis.

A multiple regression analysis was applied to the data with categorical and continuous variables for a repeated measures design with coding of subjects by criterion scaling and vision mode by dummy coding as the fixed factor (baseline or intrusion). The distance and angle of the targets are interpreted as random continuous variables because of the random order of presentation and coverage over the site. The analysis compared the baseline to the return and the baseline to the intrusion for the targets detected. The analysis shows that the significant differences (0.001 level) in the detection times for the baseline and return are attributable to the distance, offset, and subjects but not to the mode. In contrast, the significant differences in the detection times for the baseline and intrusion are attributable to the mode, distance, and offset but not to the subjects.

The data for the false alarm rate of each subject, as determined from the number of non-targets falsely detected for the vision modes, are too sparse for statistical analysis. However, the false alarm rate was practically nil for the direct vision (3.1%), while 4 of 8 subjects detected one to two false targets in ten possibilities each in the indirect (HMD) mode for an overall false alarm rate of 14.1%. In all cases, the subjects recognized that the detection was false when the target did not drop after their button push, and they reported that fact to the experimenter.

In summary, the analysis shows that there is practically no effect of the experimental order on the detection performance with direct vision. The mean detection times increases with target bearing. However, the detection times are longer with the indirect vision system, for which the mean detection time does not exceed 10 seconds.

APPENDIX D

BOX PLOTS FOR DETECTION TASK ATTENTION ALLOCATION QUESTIONNAIRE SCORES

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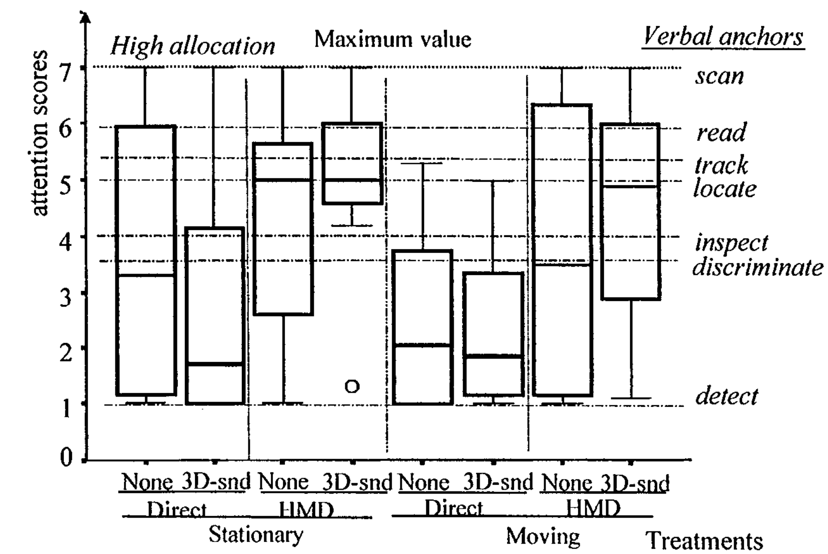

Figure D-1. Visual Channel Attention Allocation.

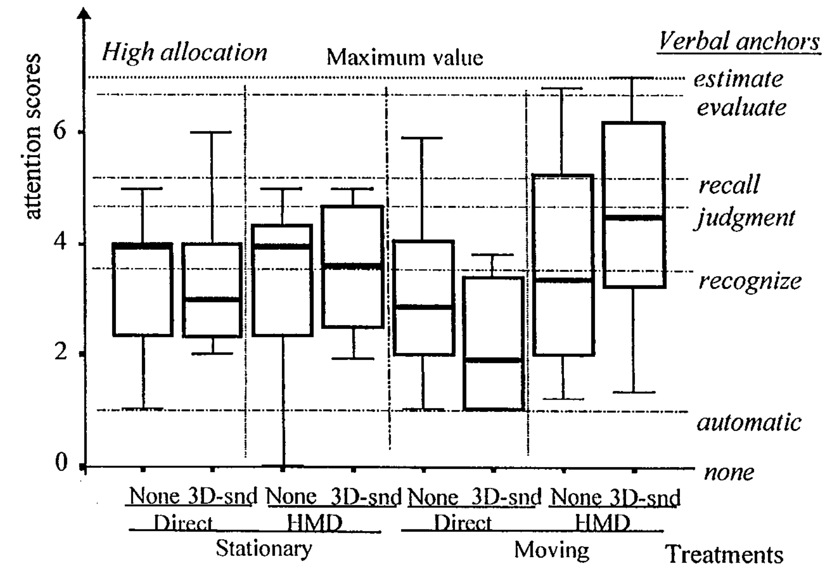

Figure D-2. Cognitive Channel Attention Allocation..

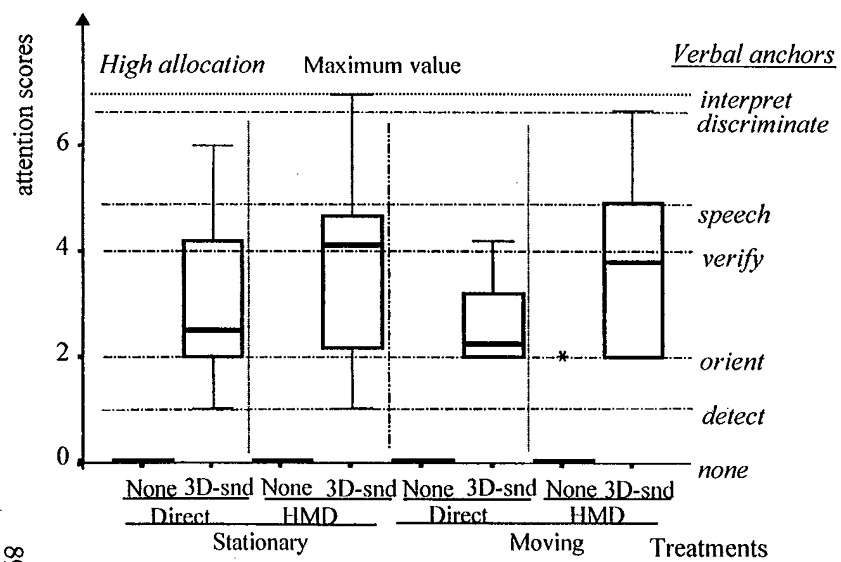

Figure D-3. Auditory Channel Attention Allocation.

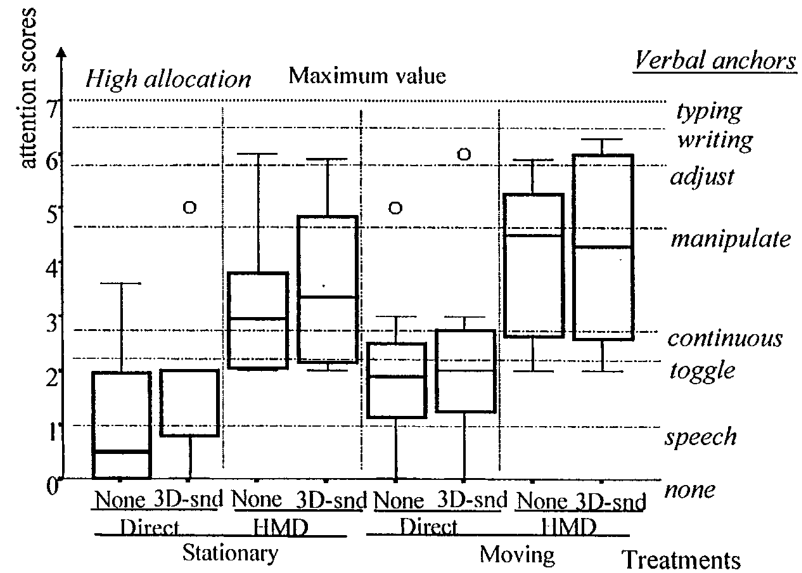

Figure D-4. Psychomotor Channel Attention Allocation.

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APPENDIX E

BOX PLOTS FOR IDENTIFICATION TASK ATTENTION ALLOCATION QUESTIONNAIRE SCORES

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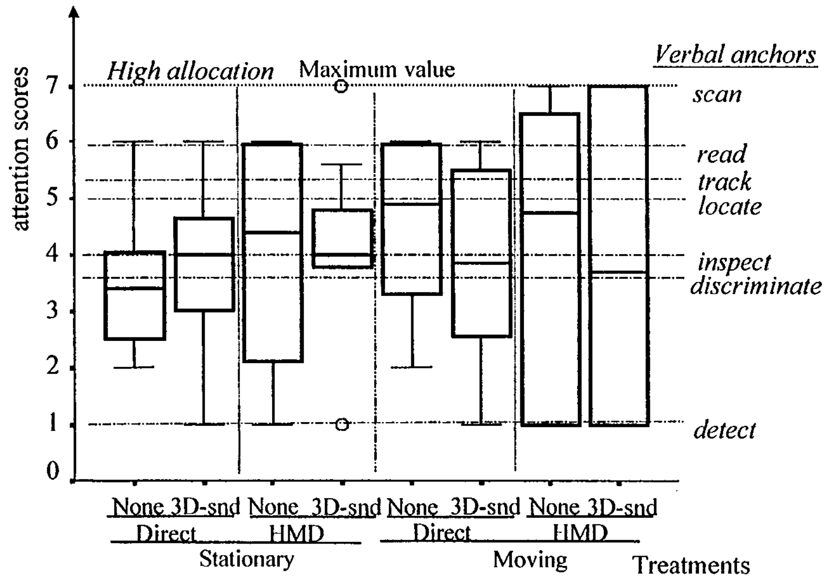

Figure E-1. Visual Channel Attention Allocation.

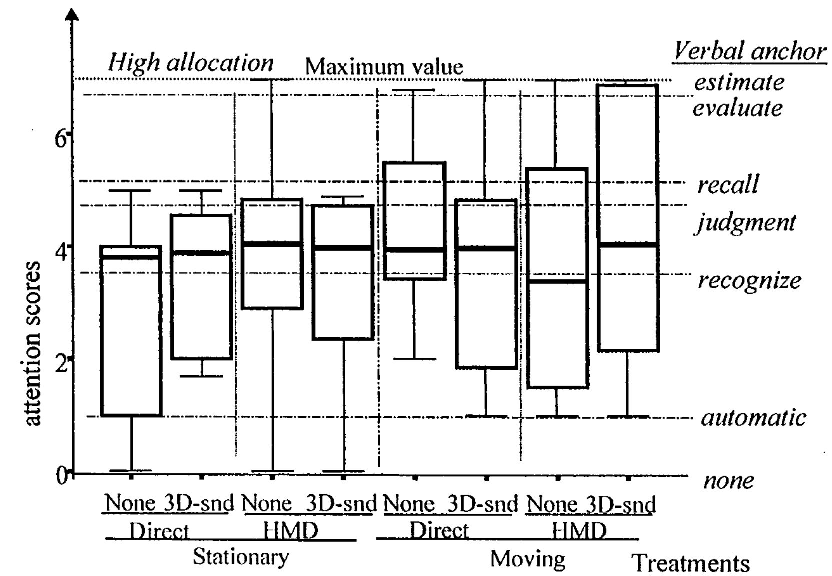

Figure E-2. Cognitive Channel Attention Allocation.

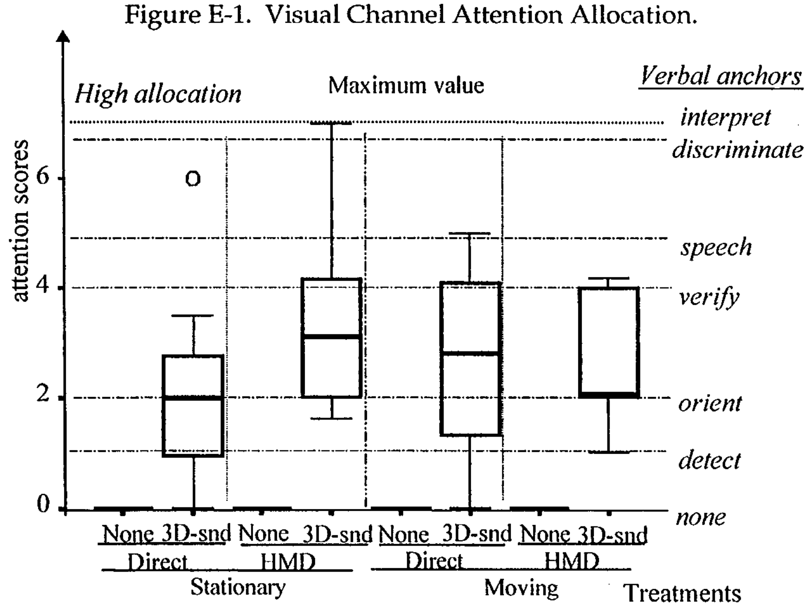

Figure E-3. Auditory Channel Attention Allocation.

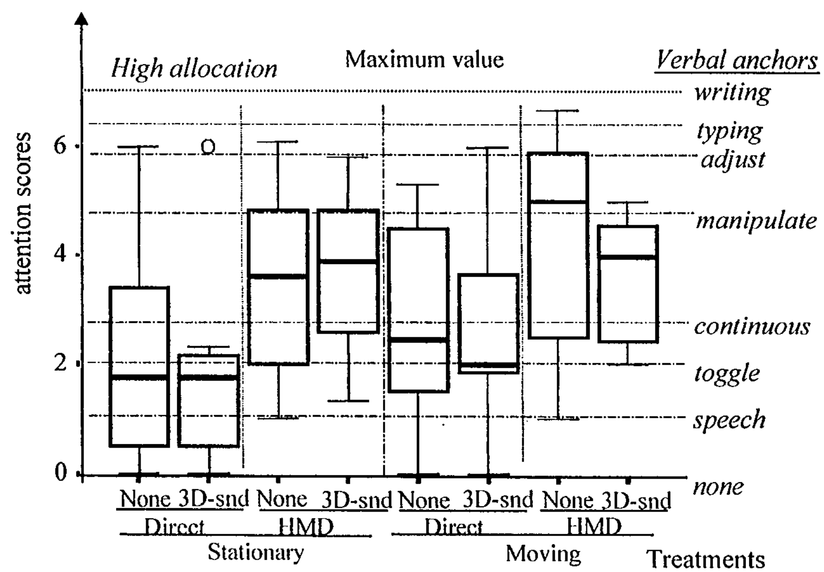

Figure E-4. Psychomotor Channel Attention Allocation.

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APPENDIX F

BOX PLOTS FOR PERCEIVED WORKLOAD
QUESTIONNAIRE SCORES

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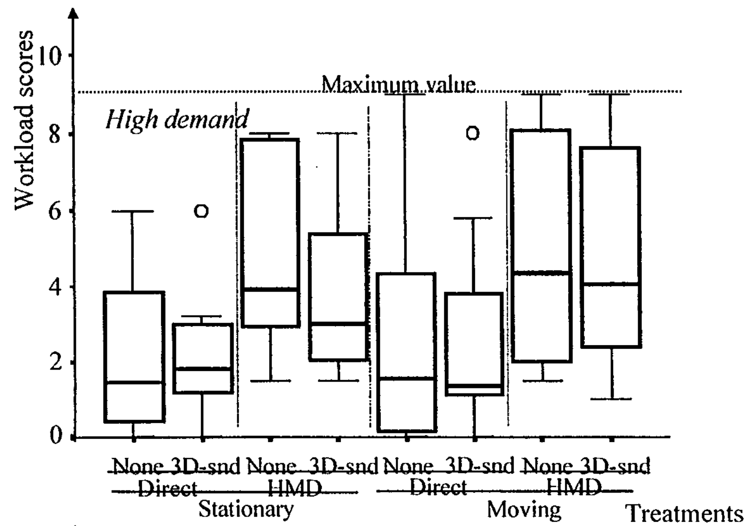

Figure F-1. TLX Mental Demand.

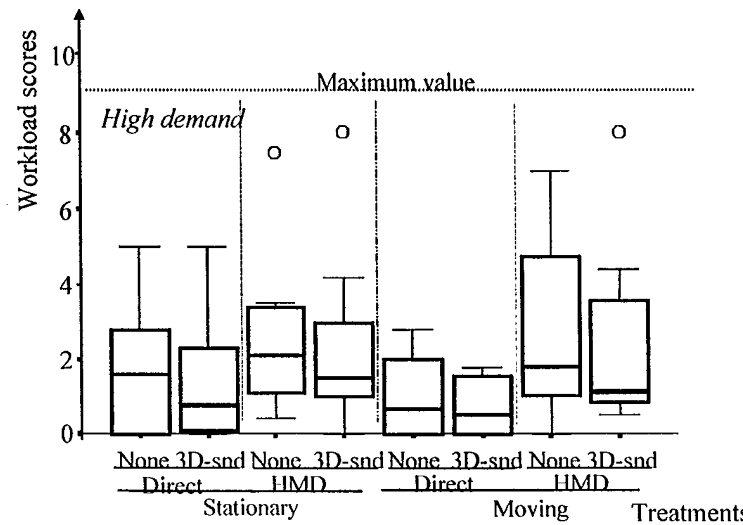

Figure F-2. TLX Physical Demand.

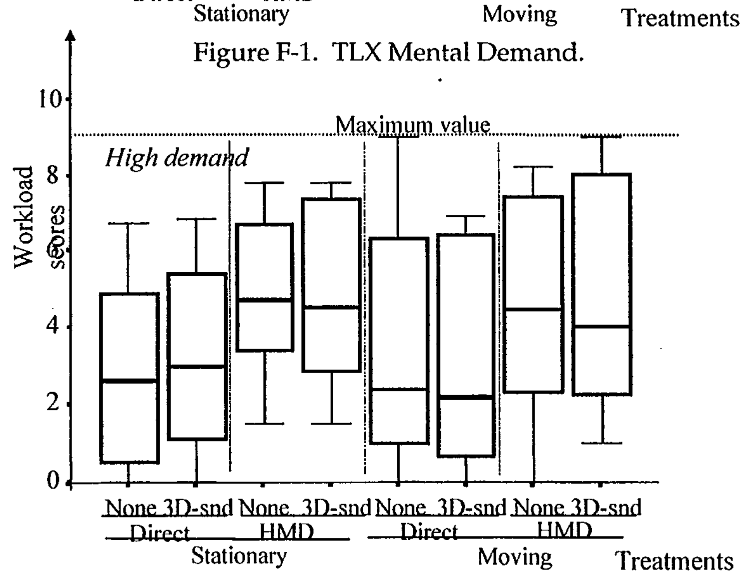

Figure F-3. TLX Temporal Demand.

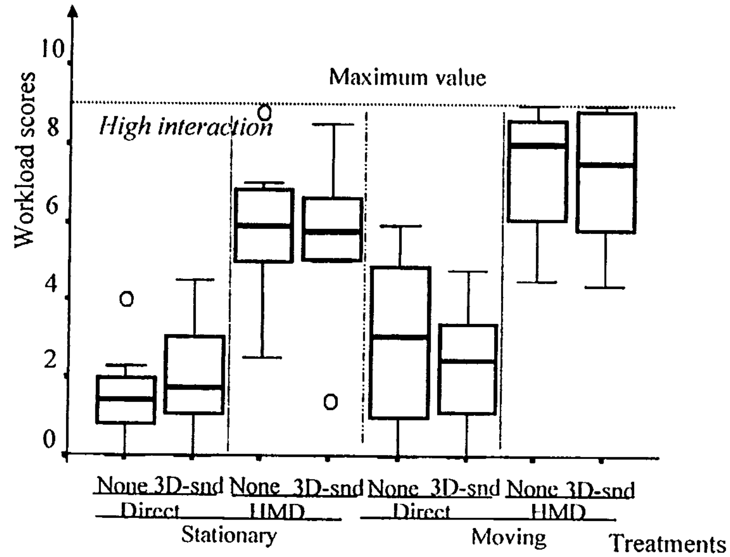

Figure F-4. TLX Interaction Effort.

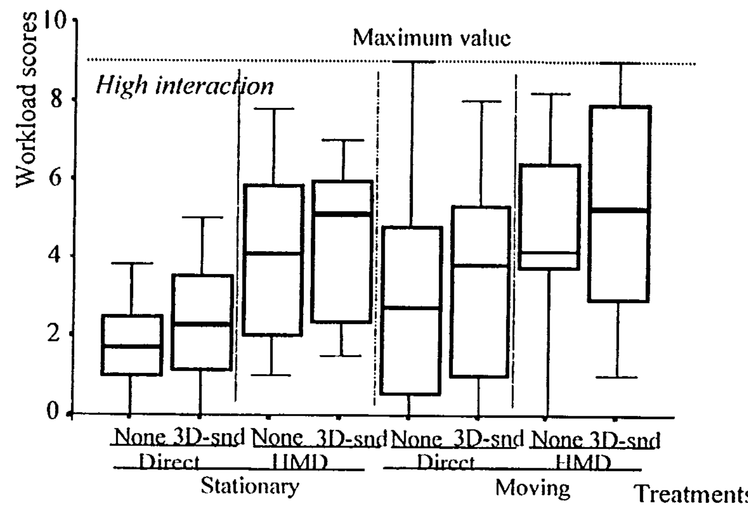

Figure F-5. TLX Interaction Performance.

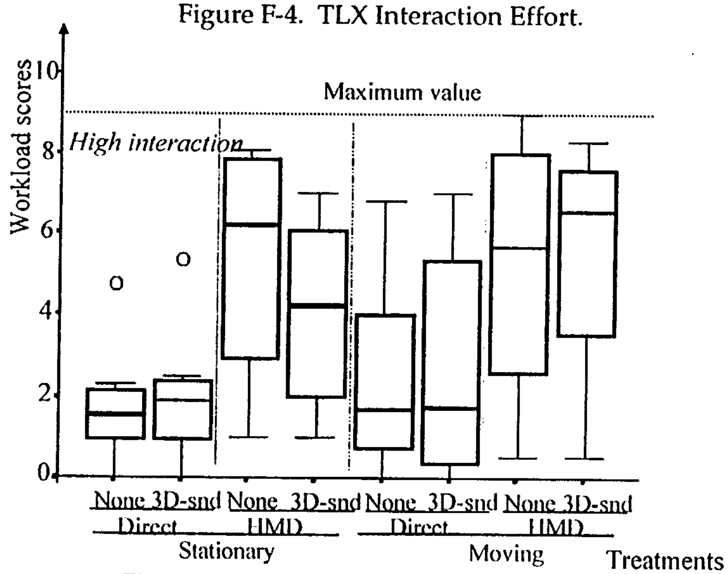

Figure F-6. TLX Interaction Frustration.

APPENDIX G

BOX PLOTS FOR SITUATIONAL AWARENESS QUESTIONNAIRE SCORES

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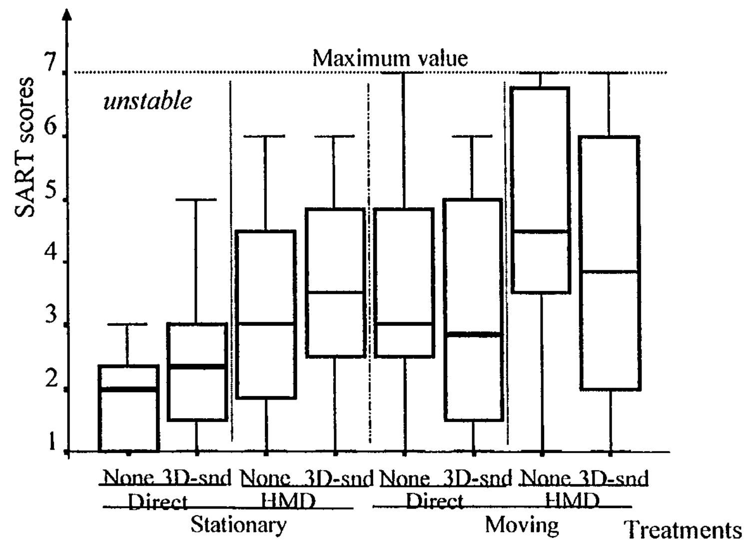

Figure G-1. SART Instability Demand.

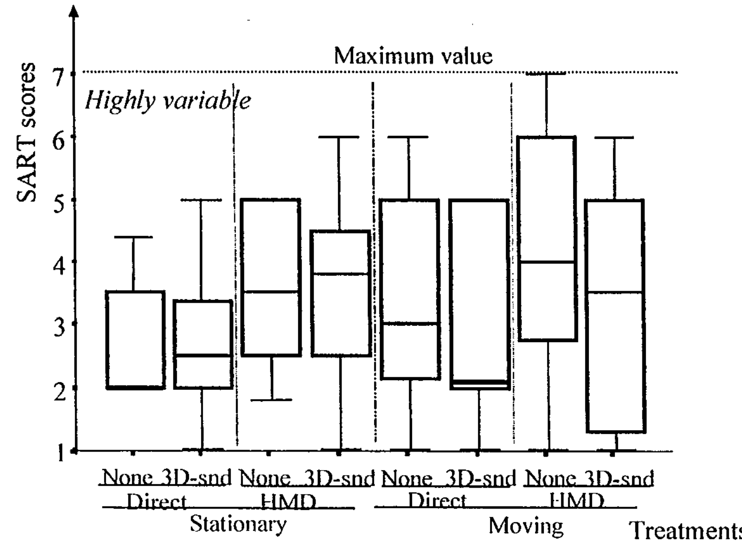

Figure G-2. SART Variability Demand.

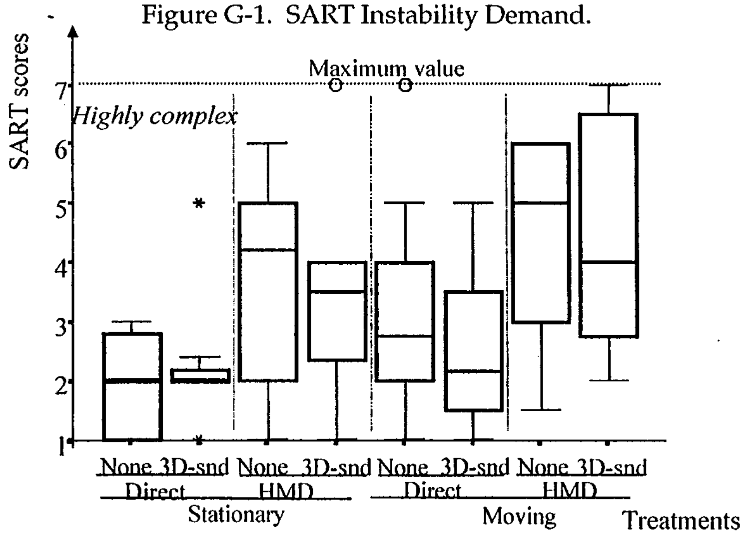

Figure G-3. SART Complexity Demand.

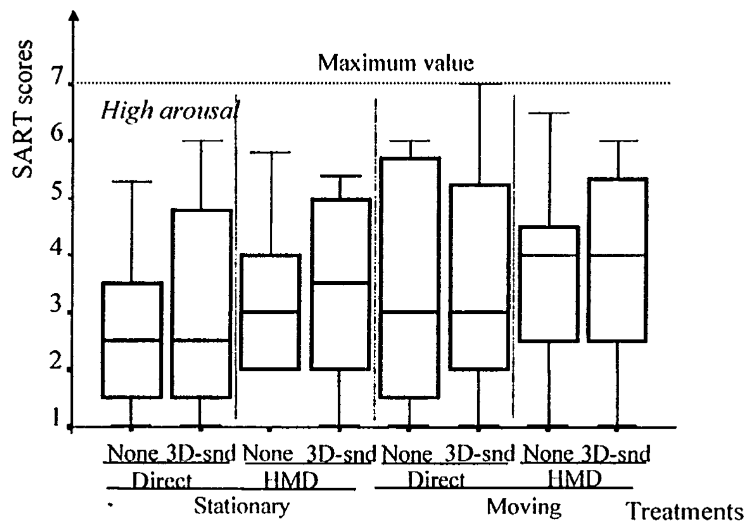

Figure G-4. SART Arousal.

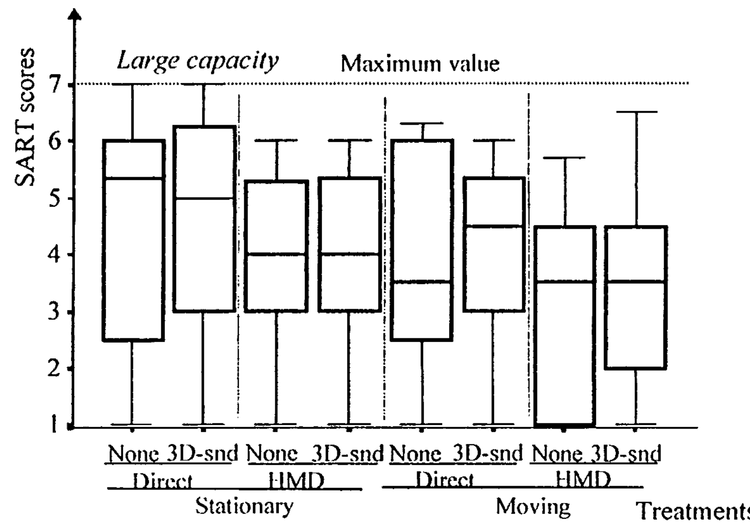

Figure G-5. SART Spare Mental Capacity.

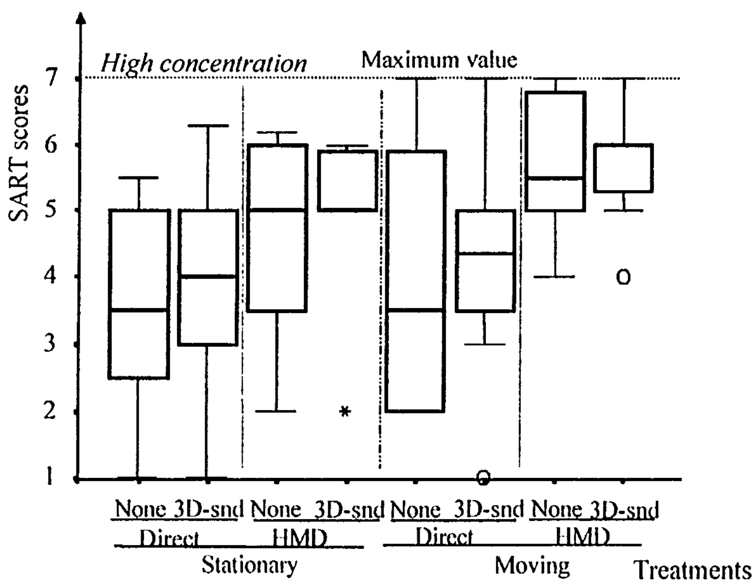

Figure G-6. SART Concentration.

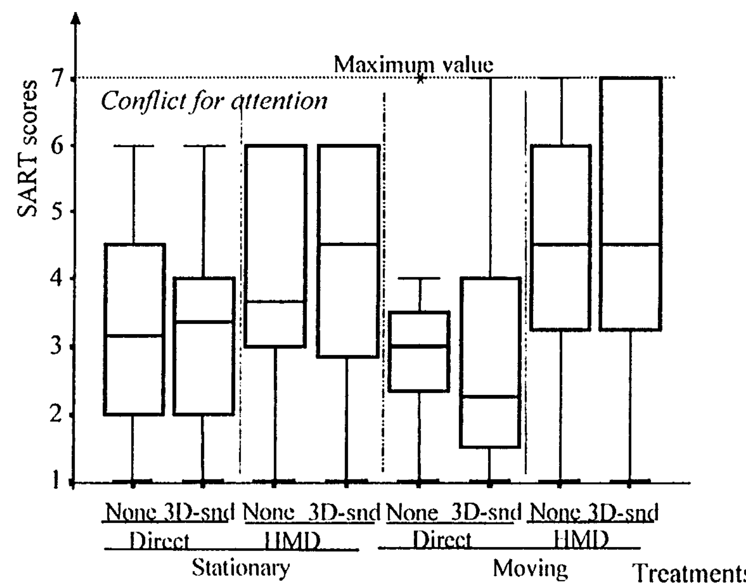

Figure G-7. SART Division of Attention.

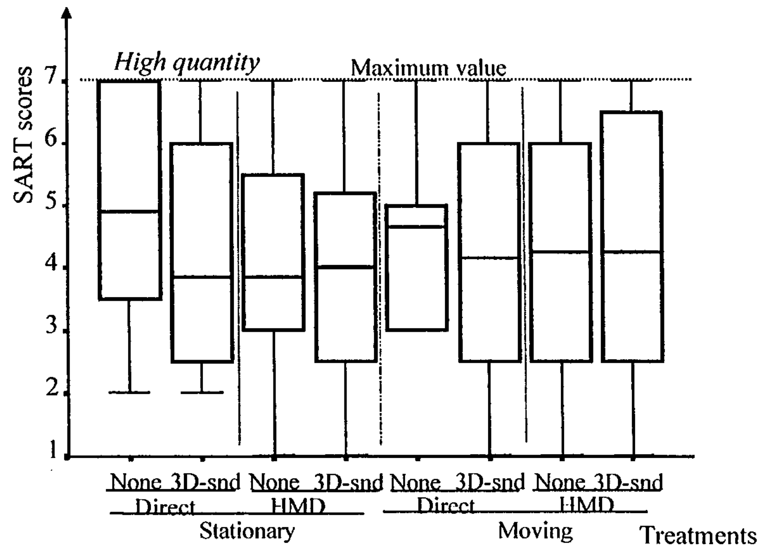

Figure G-8. SART Information Quantity.

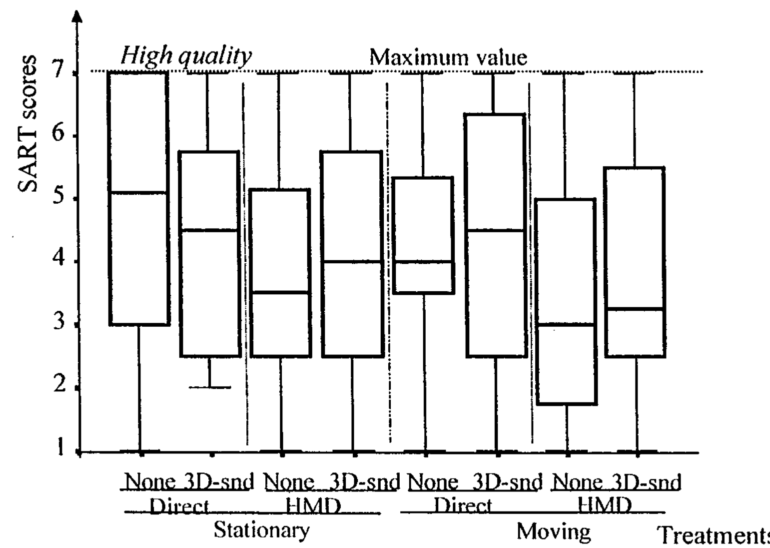

Figure G-9. SART Information Quality.

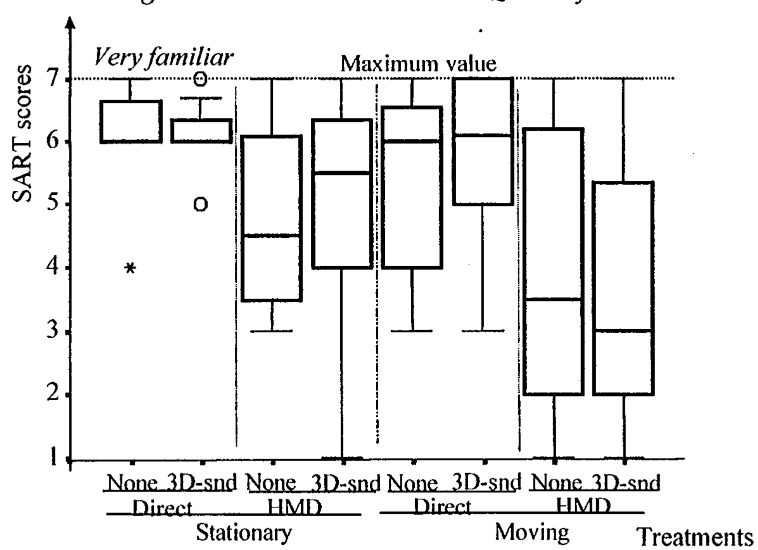

Figure G-10. SART Familiarity.

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1	CHIEFARMY RSCH INST AVIATION R&D ACTIVITY ATTN PERI IR FORT RUCKER AL 36362-5354
1	AF FLIGHT DYNAMICS LAB ATTN AFWAL/FIES/SURVIAC WRIGHT PATTERSON AFB OH 45433
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13. ABSTRACT *(Maximum 200 words)*

The effect of indirect vision systems on target detection and recognition is of interest to designers of future combat vehicles. In a field study, eight participants detected and identified "pop-up" targets on an outdoor experimental facility from a stationary and a moving vehicle while using a head-mounted display (HMD) and direct viewing as a control, with and without sound localization. A head-slaved camera mounted on top of the vehicle provided the image to the HMD. With sound localization provided by localized auditory cueing, the computer-controlled audio tones (intermittent at a 0.5-second interval) appeared to originate from the location of the target.

The results are that more targets were detected with direct viewing than with the HMD and from the stationary position than the moving vehicle. Although more targets were detected with direct viewing from the stationary vehicle without cueing, sound localization improved target detection in all other treatments. Similar comments apply to identification from the stationary position; however, fewer targets were identified from the moving vehicle with sound localization than without. The advantages of auditory cueing for target detection may have been limited by the choice of an intermittent tone for sound localization and the restricted search sector used in the experiment.

Ratings of task attention loading show that increased attention was needed for the detection task with sound localization, especially with the HMD. This is also true for the identification task. Workload test battery ratings show a significant increase in perceived workload with the HMD as compared to the direct vision. A test of situational awareness shows significant effects with decreasing trends in perceived stability and familiarity and an increased need to concentrate when one is using the HMD in the moving vehicle. Furthermore, most of the participants reported a general discomfort associated with motion sickness while in the moving vehicle with the HMD. There was no significant change in heart rate with test mode, suggesting that there was no impact of metabolic work on their performance. As a result of the study, the participants rated direct viewing as more useful than the HMD and the sound localization as being of more use with the HMD than with direct viewing.

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