ARMY RESEARCH LABORATORY

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Abstract

The command and control vehicle (C2V) was developed to support U.S. Army tactical operation centers in heavy forces. The requirements for the C2V stipulate that it must support mobile operations and that it must support command and control (C2) from within the confines of the vehicle. However, in early testing, some human operators exhibited motion sickness during moving operations. As a result, the Human Research and Engineering Directorate of the U.S. Army Research Laboratory, in cooperation with the National Aeronautics and Space Administration's Life Sciences Division, was directed to perform a study to quantify the incidence and severity of motion sickness and any associated performance decrement. The study would discriminate between motion effects in the C2V in parked, moving, and short halt in each seat in three seat configurations.

Twenty-four soldiers were exposed to each of 12 seats (four seats in three vehicle configurations) for a 4-hour "cell." During a cell, subjects completed a motion sickness and mood scale and the Delta cognitive battery. Half the subjects were also instrumented to record physiological correlates of motion sickness. Each cell included an initial (parked) administration of the test batteries followed by two test batteries while moving and three test batteries during short halts.

Fifty-five percent of the subjects reported an average motion sickness score, indicating moderate to severe symptoms. Symptoms were not mitigated by short halts. One subject was withdrawn from the study because of severe and persistent symptoms.

Performance was significantly worse during moving operations than in parked, with a partial recovery during short halts. Performance degradation was comparable to blood alcohol equivalencies at or above 0.08% in 35% of the soldiers during movement and 22% during short halts.

There was no significant difference between seat or vehicles in any of the measurements.

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Objectives

The purpose of this project was to use National Aeronautics and Space Administration (NASA) technology to assist the U.S. Army in assessing motion sickness incidences and their effects on soldier performance and mood states within the command and control vehicle (C2V). Specific objectives were to (a) determine if there was a significant difference among three internal configurations of the C2V or between seats within these vehicles; (b) determine if there was a significant difference between the park, move, or short-halt field conditions; and (c) validate a method of converging indicators developed by NASA to assess the environmental impact of long duration space flight on crew members, using a large sample of subjects during ground-based operational conditions.

Methods

Twenty-four soldiers (16 men and 8 women) participated for 15 days: 2 days of classroom instruction in an office facility, 12 days of field tests in the C2V (all subjects rode in each seat of each vehicle), and 15 minutes of post-field test performance measures. During a test "cell," subjects completed the tests six times under the following conditions: (a) once immediately after entering the vehicle (stationary for 15 to 20 minutes), (b) twice while the vehicle was moving (the end of a roughly 40-minute road march over mixed secondary roads and tank trails), and (c) three times with the vehicle stationary immediately after a road march. Three different vehicle configurations were tested: (a) oblique, in which the seat closest to the front faced forward and the remaining three seats were at a 20° angle from the direction of travel; (b) perpendicular, in which the front seat also faced forward, but the remaining three seats were at a 90° angle; and (c) 4-forward, in which all four seats faced forward. Physiological data were collected on those days when subjects were assigned to Seat 1 or Seat 3. NASA test batteries, mood and diagnostic scales were collected only during the park, two of the moves (1 and 4), and three of the short-halt conditions (2, 3, and 4).

Results

Motion sickness symptoms, ranging from slight to severe, were reported by all 24 subjects. Only 15% of the subjects experienced frank vomiting, but these episodes tended to recur within the same individuals. The most frequently reported symptom was drowsiness (60% to 70% of subjects), followed by headache (40% to 56%), sensations of increased warmth unrelated to ambient air temperature (40% to 45%), nausea (35% to 42%), and uncomfortable stomach sensations approaching nausea (20%). Although no significant differences were found

between vehicles or seats, all metrics showed significant changes (increased symptoms and degraded performance and mood) when vehicles moved. A performance decrement standard, defined as at least 5% decrease from baseline in five of the seven performance subtests, occurred in 11 of the 24 subjects. A performance decrement >5% was observed in 22 of the 24 subjects for at least two subtests and in more than 20 subjects for at least three subtests. A second criterion for evaluating performance decrements was the calculation of a blood alcohol level equivalency (BAL%). During the move condition, eight subjects showed BAL% levels of >0.08 (the legal limit of alcohol consumption in most states), and 19 subjects showed a BAL% of >0.025 (shown to be associated with significantly impaired performance in aviation simulators). Physiological data reflected changes in field conditions and were directly related to individual differences in motion sickness susceptibility, overall performance levels, and mood states.

Conclusions

This report contains sufficient information needed to answer the questions posed by the Army and to successfully validate assessment methods developed by NASA, thereby accomplishing important goals for both Federal agencies. The preponderance of evidence provided by multiple converging indicators used in this study has led to the following conclusions:

1. There was no significant difference between vehicle configurations;

2. There was negative impact on crew performance and health when subjects attended to visual computer screens while the vehicle was moving;

3. The severity of symptoms and performance degradation was not substantially reduced by intermittent short halts; and

4. Performance and mood were impaired in the vehicle during the park condition, relative to pre- and post-tests conducted in a classroom facility.

The methodology demonstrated here may also be useful for examining the impact on soldiers in other land, sea, and air vehicles for which command and control functions, similar to those of the C2V, are planned. The examination of changes in physiological responses, performance, and mood states of soldiers in these environments also provides a more comprehensive assessment of the efficacy of countermeasures for improving individual crew health and operational efficiency. Autonomic conditioning (AFTE) may be one option for mitigating negative environmental effects on soldiers and astronauts when the use of medication is untenable and when modification of the vehicle, crew tasks, or sleep schedules is not feasible.

THE EFFECTS OF THE COMMAND AND CONTROL VEHICLE (C2V) OPERATIONAL ENVIRONMENT ON SOLDIER HEALTH AND PERFORMANCE

INTRODUCTION

The purpose of this project was to use National Aeronautics and Space Administration (NASA) technology to assist the U.S. Army Program Executive Office for Ground Combat and Support Systems, Product Manager's Office, Bradley fighting vehicle system (PM-BFVS), in assessing motion sickness incidences within the command and control vehicle (C2V). The C2V is an armored tracked vehicle that contains four workstations in an enclosed crew compartment (i.e., no outside view), where military personnel are expected to perform command and control functions during combat conditions. This research meets NASA's Human Exploration and Development of Space (HEDS) objectives of transferring space technology to earth-based applications and developing technology designed to enhance crew health and performance in space.

A recently completed study (Cowings, Toscano, & DeRoshia, 1998) conducted at Yuma Proving Ground (YPG), Arizona, demonstrated that NASA's methods employed for assessing environmental impact on soldier health and performance could be successfully conducted during operational field test conditions. Eight active duty military men (U.S. Army) at YPG participated in this study. All subjects were given baseline performance tests while their physiological responses were monitored on the first day. On the second day of their participation, subjects rode in the C2V while their physiological responses and performance measures were recorded. Self-reports of motion sickness were also recorded.

Results showed that only one subject experienced two episodes of vomiting. However, seven of the eight subjects reported other motion sickness symptoms. The most frequently reported symptom was drowsiness, which occurred a total of 19 times. Changes in physiological responses were observed relative to motion sickness symptoms reported and the different environmental conditions (i.e., level, hills, and gravel) during the field exercise. Performance data showed an overall decrement during the C2V exercise. These findings suggest that malaise and severe drowsiness can potentially impact the operational efficiency of a C2V crew. However, a number of variables (e.g., individual's sleep duration before the mission or previous experience in the vehicle) were not controlled and may have influenced the results. Most notable was the fact that subjects with prior experience in the C2V all occupied Seat 4 (located farthest forward), which was anecdotally reported to be the least provocative position. Nonetheless, it was possible to determine which factors most likely contributed to the results observed. It was concluded that conflicting sensory information from the subject's visual displays and movements of the vehicle during the field exercise significantly contributed to motion sickness symptoms observed. The results are consistent with earlier studies conducted at Camp Roberts National Guard Training Center, California, by the U.S. Army Research Laboratory (ARL) (Tauson, Doss, Rice, Tyrol, & Davidson, 1995) and at Aberdeen Proving Ground (APG), Maryland (Beck & Pierce, 1996).

The objectives of the YPG study were successfully met. The use of three converging indicators (physiological monitoring, subject self-reports of symptoms, and measurements of performance) was an effective means of evaluating the incidence of motion sickness and the impact on crew operational capacity in the C2V. It was recommended that a second study be conducted to further evaluate the effect of seat position and orientation on motion sickness susceptibility. The specific objectives of the present study were to

1. Determine if there was a significant difference among three internal configurations of the C2V or between seats within these vehicles;

2. Determine if there was a significant difference between the park, move, or short-halt field conditions; and

3. Validate a method of converging indicators developed by NASA to assess the environmental impact of long duration space flight on crew members, using a large sample of subjects during ground-based operational conditions.

METHODS

Subjects

Twenty-four active duty military personnel (8 women and 16 men, ages 18 to 34) participated in this study. Subjects were medically qualified for participation in these tests, following a review of their records by Army doctors to detect any pre-existing condition that might put them at risk. Subjects were briefed about the experimental procedures, and their voluntary consent was obtained before tests began. Subjects were instructed to abstain from consuming alcohol or medication (i.e., anti-motion sickness drugs or antihistamines) throughout their participation in this study. The research protocol was reviewed and approved by the Institutional Review Boards (IRB) of both NASA Ames Research Center and ARL.

Apparatus

Physiological Measures

The autogenic-feedback system-2 (AFS-2) is a portable belt-worn ambulatory monitoring system designed to monitor human physiological responses. This system was developed and tested on astronauts during a space shuttle mission in 1992. The following physiological measures were recorded on the AFS-2 (see Figure 1), which includes a garment, transducers, biomedical amplifiers, a digital wrist-worn feedback display, and a cassette tape recorder. The entire instrument is powered by a self-contained battery pack.

1. Electrocardiograph (ECG): Pre-gelled disposable electrodes were placed on the chest just below the left and right clavicles (distally) and on the left midclavicular line over the fourth intercostal space.

2. Respiration Rate (RR): Respiration amplitude and frequency were measured with a piezoelectric transducer attached to the garment with snaps over the chest.

3. Finger Pulse Volume (FPV): Relative changes in peripheral vasomotor activity were monitored using an infrared photoplethysmograph. A miniature light-emitting diode (LED) mounted within a ring transducer was placed on the inner surface of the small finger on the left hand.

4. Skin Temperature (ST): A solid state temperature transducer (Analog Devices, model AD590) was mounted within the same ring as the FPV transducer. ST was used as a relative measure of peripheral blood volume.

5. Skin Conductance Level (SCL): Absolute changes in the electrolytic properties of the skin were monitored from disposable electrodes. These pre-gelled, self-adhesive electrodes were mounted on the volar surface of the left wrist.

6. A triaxial accelerometer was used to measure head and upper body movements of subjects during field tests within the C2V. This device was attached to the soldiers' hats or helmets with tape.

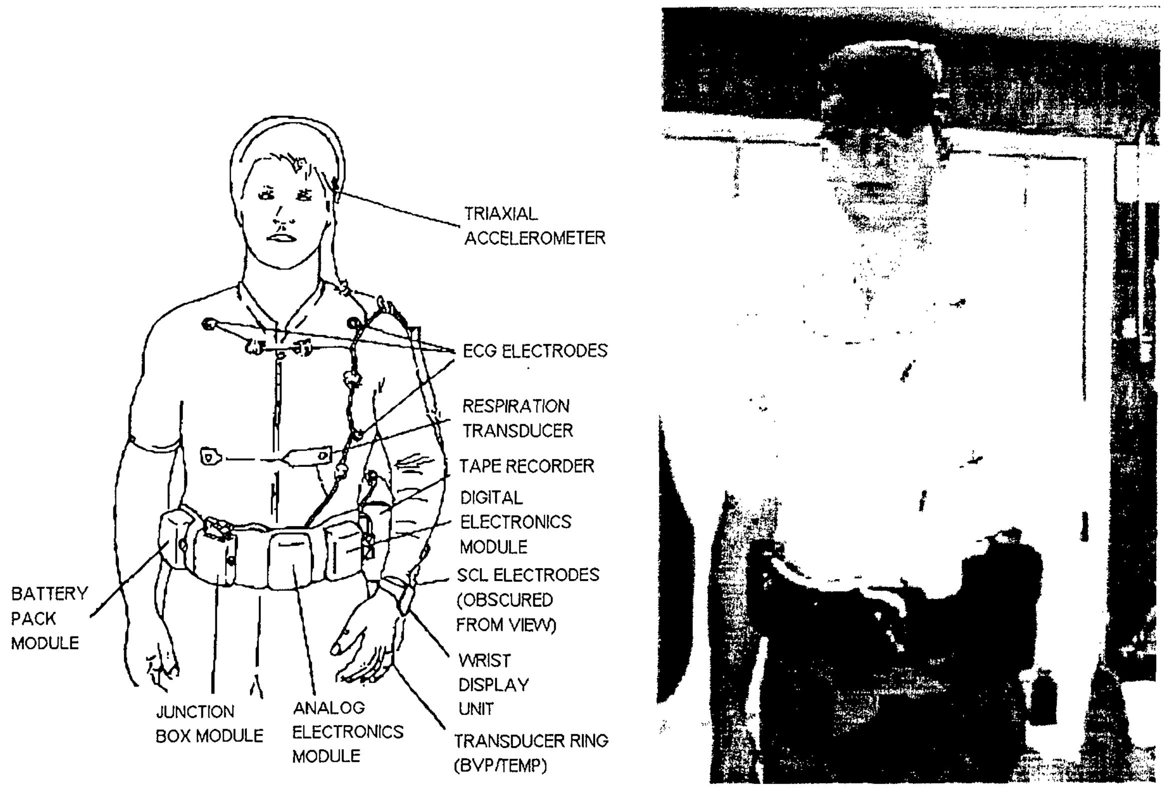


Figure 1. An illustration of the autogenic-feedback system-2 (AFS-2) and a photograph of a soldier wearing the AFS-2.

Delta Performance Test Battery

The Delta human performance measuring system is an upgraded software version of the automated performance test system (APTS), which was developed as an assessment tool for human performance (Kennedy, Jones, Dunlap, Wilkes, & Bittner, 1985). The APTS was developed with emphasis on within-subjects, repeated measures designs and has proved both reliable and valid in a number of investigations; administration takes approximately 15 minutes or less, depending upon the test battery configuration. The Delta Test Battery has been used extensively to study the effects of environmental and chemical stressors on human performance. Our own research group has used the APTS version of this computer-based performance task battery to successfully evaluate the effects of promethazine on human performance and motion sickness susceptibility (Cowings et al., 1996) and to evaluate the effects of confinement and exercise countermeasures in simulated weightlessness (bed rest) studies (DeRoshia & Greenleaf, 1993). For some subtests, the performance metric was "accuracy" (number of correct responses minus number of errors) or "speed" (responses per second). The manual dexterity tests were evaluated on the number of alternate key presses in the time allowed. A brief description of the seven subtests used in this experiment is provided next.

Three-choice Reaction Time (REACT3, 60 seconds)

This test involved the presentation of a visual stimulus and measurement of response latency to the stimulus. The subject's task was to respond as quickly as possible with a key press to a simple visual stimulus. On this test, three "outlined" boxes were displayed and one of the three boxes was "filled." A short tone preceded the filling of a box to signal that a "change" in the status of a box was about to occur. The box changed from "outlined" to "filled." The subject was required to scan the boxes for the change and then press the numeric key corresponding to the box that had changed. This test measures response latency between the presentation of the stimulus and the response in milliseconds (metric = speed).

Code Substitution (CODSUB, 75 seconds)

The computer displayed nine characters across the top of the screen. Beneath them, the numbers 1 through 9 were displayed within parentheses. The subject's task was to associate the number with the character above it. This is called the subject's "code." Under the code were two rows of characters with empty parentheses beneath them. The subject responded by pressing the number associated with the character from the code above. When the subject completed a row, the bottom row moved to the top, and a new row appeared below. This is a mixed associative memory and perceptual test with visual search encoding-decoding, which incorporates memory recall and perceptual speed (metric = accuracy).

Pattern Comparison (PATRNC, 75 seconds)

This task involves comparing two patterns of asterisks that are displayed on the screen simultaneously. The subject's task was to determine if the patterns are the same or different and to respond by pressing the "S" or "D" key. This is a test of integrative spatial function and may be compared to the ability to recognize changes in radar screen or map displays (metric = accuracy).

Preferred Hand Tapping (PHTAP, 10 seconds)

In this test, the subject was required to press the indicated keys as fast as possible with two fingers of the preferred or dominant hand. Correct responses were based on the number of alternate key presses made in the allotted time.

Non-preferred hand tapping was similarly conducted using the non-dominant hand. These tapping tests measure manual motor skill and coordination (metric = number of alternate key presses).

Grammatical Reasoning (REASON, 90 seconds)

Stimulus items were sentences of varying syntactic structure (e.g., A precedes B) accompanied by a set of letters (e.g., AB). The sentences were generated from possible combinations of five conditions: (a) active versus passive wording; (b) positive versus negative wording; (c) key words such as "follows" and "precedes"; (d) order of appearance of the two symbols within the sentence; and (e) order of the letters in the simultaneously presented symbol set. The subject's task was to read and comprehend whether the sentence correctly described the sequence of symbols that appeared on the screen to the right of the sentence. The subject responded by pressing the "T" (true) or "F" (false) key. This test measures cognitive reasoning, logic and verbal ability and assesses an analytical function (metric = accuracy).

Spatial Transformation (MANIKIN, 60 seconds)

This test presents a figure of a sailor on the screen with a box below his feet and a box in each hand. A pattern (♥♥♥♥♥♥ or ♦♦♦♦♦♦) appears in the box below, which matches the pattern in the box in one of his hands. The figure stands either facing away or toward the subject (right side up or upside down). The objective of this task is to determine which hand (right or left) matches the objects that appear in the box upon which the sailor is standing. The subject responds by pressing one of the two arrow keys (i.e., to indicate left or right hand). This test measures the ability to spatially transform mental images and determine the orientation of a given stimulus (metric = accuracy).

Symptom Diagnostic Scale (60 seconds)

At specific time intervals, subjects within the C2V were asked to report (via their computers at their workstations) any symptoms they were experiencing while using those computers. A computer program allowed the subject to rate his or her own symptoms using a standardized diagnostic scoring procedure referred to as the "Coriolis Sickness Susceptibility Index" or CSSI (Graybiel, Wood, Miller, & Cramer, 1968; Cowings, Suter, Toscano, Kamiya, & Naifeh, 1986). Table 1 shows the questions presented to each subject.

The presence or absence and strength of symptoms were assessed subjectively by the subject (none "0," mild "1," moderate "2," or severe "3"). These symptoms included drowsiness, sweating, salivation, pallor, and nausea. Other symptoms were rated as additional qualifying symptoms (AQS) and were scored as "none, mild, or moderate" levels only. These included increased warmth, dizziness, and headache. Stomach sensations were evaluated on five levels. Stomach awareness was described as not nausea and not particularly uncomfortable but as an increased awareness of the stomach (e.g., hunger). It was scored as either none (0) or mild (1). Stomach discomfort was described as not nausea but becoming increasingly uncomfortable (e.g., lump in the throat or stomach distended by gas). It was scored as either none (0) or moderate (2). Nausea was reported when it could clearly be differentiated from stomach awareness and stomach discomfort and was reported as none (0), mild (1), moderate (2), or severe (3). Frank vomiting was indicated as "yes" or "no" and was enumerated by responding to the question, "how often?"

Table 1

Symptom Diagnostic Scale

Severity level	None 0	Mild 1	Moderate 2	Severe 3
Are you feeling warmer?				--
Do you have any dizziness?				--
Do you have a headache?				--
Are you drowsy?				
Are you salivating more?				
Do you have facial pallor?				
Are you sweating?				
Do you feel stomach awareness?			--	--
Do you have stomach discomfort?		--		--
Do you have any nausea?				
Have you vomited today?	yes_____		no_____	
If yes, how often?				

Note. Dashes (--) indicate that the severity level does not apply to these symptoms.

The different symptoms and symptom severity were "weighted" automatically by the program and were totaled for each trial to determine malaise level. Symptoms of warmth, dizziness, headache, and stomach awareness (at any level) were assigned 1 point each. Mild levels of drowsiness, sweating, pallor, salivation, and moderate stomach discomfort were assigned 2 points each. Moderate levels of drowsiness, sweating, pallor, salivation, and mild nausea were assigned 4 points each. Severe levels of drowsiness, sweating, pallor, salivation, and both moderate and severe nausea were assigned 8 points each, with 16 points scored for vomiting. Motion sickness total scores > 0 and ≤ 2 points represent mild malaise; scores > 2 and < 8 represent moderate malaise; scores of 8 or higher represent severe malaise.

Mood-Sleep Test (60 seconds)

Immediately following the symptom diagnostic scale, a second program queried the subject about his or her current mood and alertness. A 10-point Visual-Analog Scale (VAS) (DeRoshia & Greenleaf, 1993) Mood Test was used to input responses to questions. The subject moved a cursor on a slide bar presented on the screen with the left or right arrow key. There were descriptive adjectives at each end of the slide bar, and the subject's task was to position the cursor to enter his or her response. A higher score indicated a more favorable response. Finally, the scale queried subjects about sleep quality by assessing trouble falling asleep and how many times they awoke during the previous night. Table 2 shows the specific mood states and sleep questions.

Table 2

Mood-Sleep Scale

Motivation	Bored	(0)----------------------- Interested	(10)
Arousal state	Sleepy	(0)------------------------Alert	(10)
Fatigue level	Weary	(0)------------------------Energetic	(10)
Ease of concentration	Very low	(0)------------------------Very high	(10)
Psychological tension	Tense	(0)------------------------Relaxed	(10)
Elation	Sad	(0)-------------------------Happy	(10)
Physical discomfort	Very high	(0)------------------------Very low	(10)
Contentedness	Unpleasant	(0)-------------------------Pleasant	(10)
Trouble falling asleep	Much worse	(0)-------------------------Much better	(10)
How many times did you wake up last night		(0-6)?	Amount___________

Vehicles

Three vehicle configurations were tested in this experiment. Vehicle 1 (oblique) had Seat 4 facing forward, and the remaining three seats were at a 20° angle from the direction of travel. Vehicle 2 (perpendicular) had Seat 4 facing forward, but the remaining three seats were at a 90° angle from the direction of travel. Vehicle 3 (4-forward) had all four seats facing toward the direction of travel. Figure 2 is a diagram of the interior seat orientation of these vehicles. Figure 3 shows the locations of the computer workstations in the oblique and 4-forward vehicles.

Oblique Perpendicular 4-forward

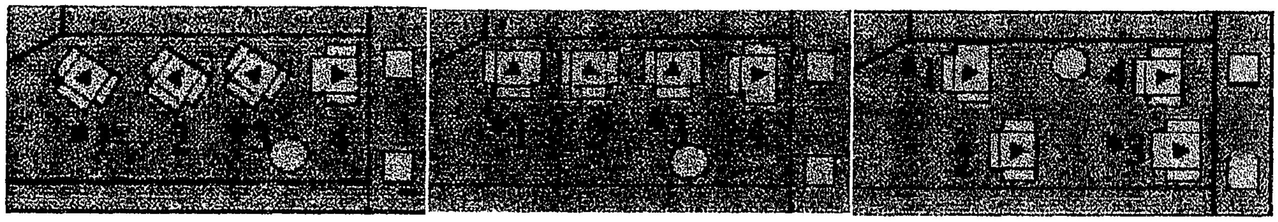


Figure 2. Seat orientations in the three vehicles.

Figure 3. Computer workstations in the oblique (left) and 4-forward (right) vehicles.

Procedures

Each subject participated for 15 days in this study which included 2 days of classroom instruction in an office facility (4 to 5 hours each day), 12 days of field tests in the C2V (4 to 5 hours per day), and 15 minutes of post-field test performance conducted 2 hours after the end of the last field test (15 subjects) or 2 days after the last field test (eight subjects).

Classroom Instruction

On the first training day, subjects received an experiment briefing from NASA and Army collaborators. During the 2 classroom instruction days, all soldiers were trained in the Delta Test Battery (four trials per day, eight total), VAS Mood Test, AFS-2 system operation, and methods for rating their symptoms. The Delta test batteries, mood and symptom reporting scales were presented on a computer system identical to those mounted in the C2V. Investigators worked with soldiers one on one (eight soldiers per day) to assure their familiarity with test procedures and operation of the AFS-2. On one day of the classroom instruction, each soldier was required to wear the AFS-2, which recorded baseline physiological data over a 4- to 5-hour period. Soldiers were also trained by ARL personnel to perform another set of tasks (not scored) using laptop computers. These additional performance tasks, Complex Cognitive Assessment Battery (Tauson et al., 1995) and manual tasks (i.e., map reading, completing questions about soldiers' common tasks), were also administered during the 4-hour field tests in the C2V. The purpose of these additional tasks was to occupy the soldiers during field tests when the NASA tasks were not being performed and to simulate functions typically performed by the C2V crew.

In addition to the subjects being trained, six individuals who were designated data collectors also received instruction about experimental procedures. The data collectors assisted the soldiers in donning and doffing the AFS-2 on the field test days. They took subjects' vital signs (pulse, temperature, and blood pressure) before and after C2V tests, wrote on daily data sheets the number of hours' sleep soldiers obtained on the previous night, and ensured that each soldier was assigned to the proper vehicle and seat. Further, the data collectors were assigned to ride with the subjects during the actual field tests. The data collectors received radioed instructions, relayed by the vehicle driver from an experimental monitoring station. In this station, an assigned duty officer called the start times for specific tasks to be performed. Data collectors were then required to inform the soldiers within their vehicles and to make written notes of any problem (i.e., vehicle, hardware, or software malfunctions) encountered during the day.

Figure 4 shows pictures of the classroom instruction setting. Here, soldiers are receiving individual instruction about the operation of the Delta batteries, mood and diagnostic scales. Laptop computers used for training about the CCAB tasks were on adjacent tables. Figure 5 shows the screen views that soldiers observed when performing the Manikin (left) and Code Substitution tasks (right). Figure 6 shows the setting for training operation of the AFS-2 ambulatory monitoring system and for teaching data collectors their required duties during the experiment.

C2V Field Tests

Following classroom training, each subject was required to ride four times in each of the three vehicles. During each C2V test, subjects were assigned to different seats in the vehicle. Figure 7 shows the scheduled activities on field test days and the distribution of tasks performed by subjects during each 4-hour test. Following an initial "park" condition of 15 to 20 minutes, when the vehicles were stationary with all soldiers aboard, the vehicles proceeded through four "move" conditions (i.e., travel over a fixed course, including secondary roads and tank trails covering flat and hilly terrain, approximately 40 minutes). These were interspersed with four "short-halt" conditions (i.e., vehicle was stationary for 15 to 20 minutes) including one short halt at the end of the field tests. Physiological data were only collected on those days when a subject was assigned to Seat 1 or Seat 3. NASA test batteries, mood and diagnostic scales were collected only during the park condition, two of the move conditions (1 and 4), and three short-halt conditions (2, 3, and 4). Physiological data tapes, computer task files, and information about each subject, as well as test schedule changes, were sent to NASA and university collaborators after the completion of each test day.

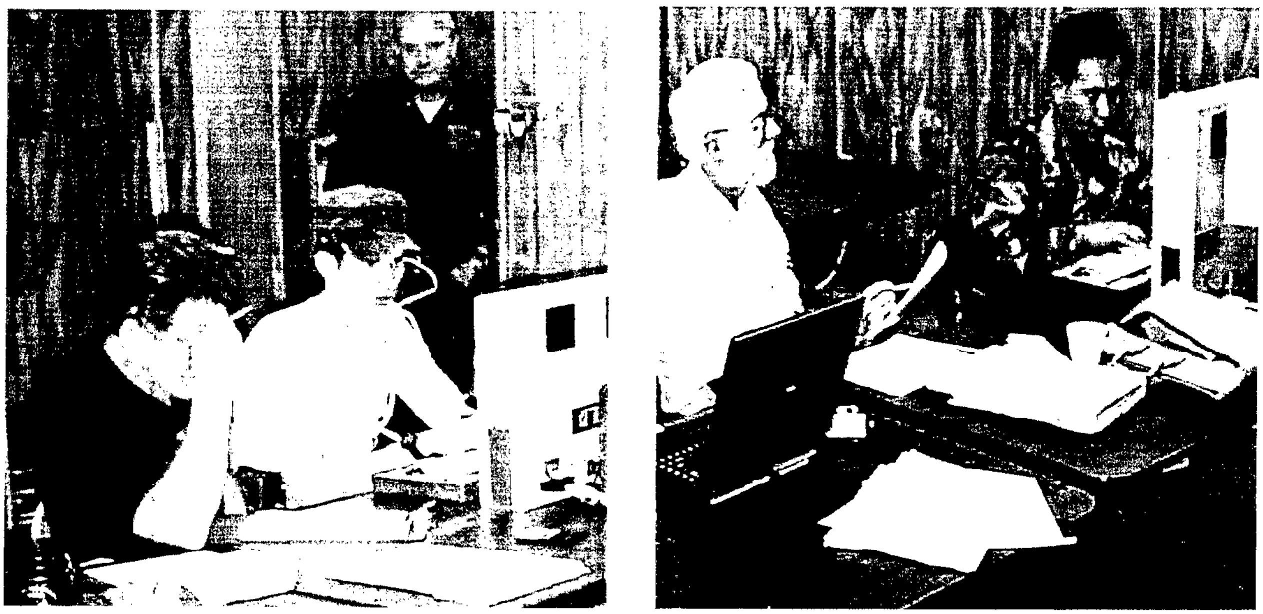


Figure 4. Training subjects in performance tasks, mood, sleep and diagnostic scales.

Figure 7 shows when the Delta battery (which included mood and diagnostic scales), manual and CCAB tasks were administered. The red and green areas indicate when the vehicle was stationary or moving. The gray areas before and after the field test show when soldiers donned and doffed the AFS-2 and when "entry" and "exit" questionnaires (e.g., prior night's sleep, medications taken, level of motivation) were administered.

An optimal experimental design required that subject assignment to vehicles and seats be counterbalanced. However, this was not possible because Vehicle 2 (perpendicular) was not available until near the end of the experiment. Vehicles 1 and 3 (oblique and 4-forward) operated with one closely following the other and with each vehicle making the same duration move and short-halt excursions whenever possible. Some of the scheduled test days were canceled and later rescheduled because of problems encountered with vehicle operations or computer hardware and software failures.

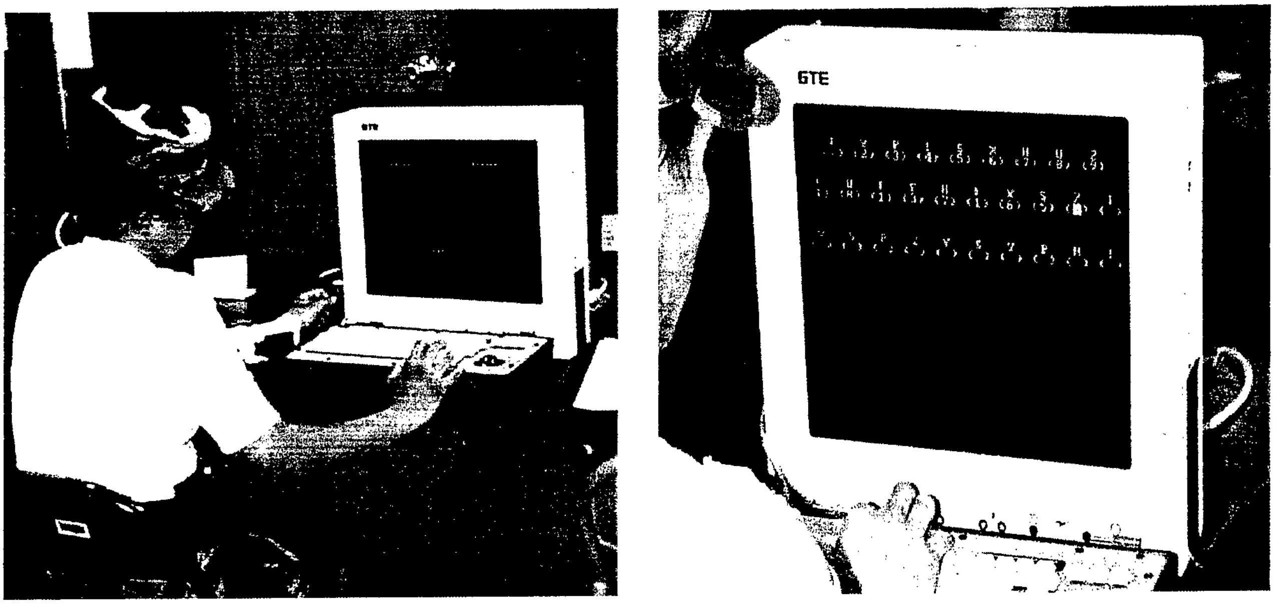


Figure 5. Soldiers performing the Manikin (left) and Code Substitution subtests (right).

Figure 6. Training data collectors and subjects about AFS-2 operation and daily procedures.

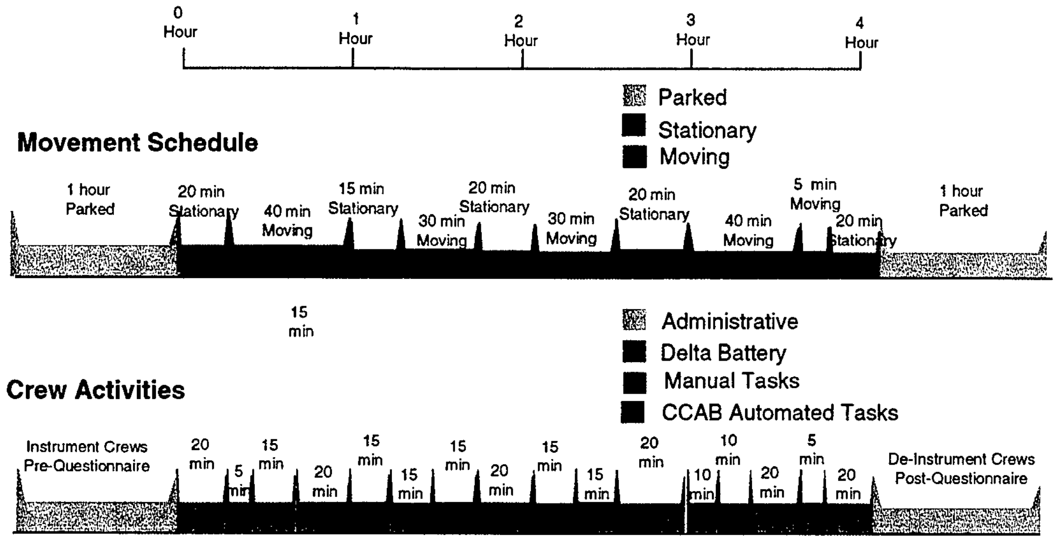


Figure 7. C2V field tests conducted over a 4-hour period.

Table 3 shows the complete experiment schedule as it was conducted over a 28-day period. The vehicles and seats were designated as V1, V2, and V3 (oblique, perpendicular, and 4-forward) and S1, S2, S3, and S4 (Seats 1 to 4). The first 4 days, labeled P-1 to P-4, represented "pilot" tests, during which field operations were tested and procedural problems resolved. The remaining days were labeled D-1 through D-24. As can be seen from this table, Vehicle 2 was not available until D-15.

Subjects 1 through 8, and 171 through 24 were always tested in the morning, between 8:00 a.m. and 12 p.m., while Subjects 91 through 16 were tested in the afternoon from 13:00 to 17:00 p.m. All subjects were tested on alternate days, allowing 1 day of rest between C2V field tests. On alternate days throughout the experiment, tests were conducted in the morning only (Subjects 171 through 24), allowing time for vehicle maintenance and repair in the afternoon.

The yellow areas in this table indicate which subjects wore the AFS-2 ambulatory monitoring system, and they indicate the vehicle and seat assignments for all subjects. The gray areas represent days when field operations were canceled and replacement tests rescheduled. Several field tests were not replaced because of individual workstation malfunction leading to loss of data or vehicle malfunction leading to abbreviated tests. Vehicle 2 (perpendicular) had the greatest number of missed field tests.

Table 3

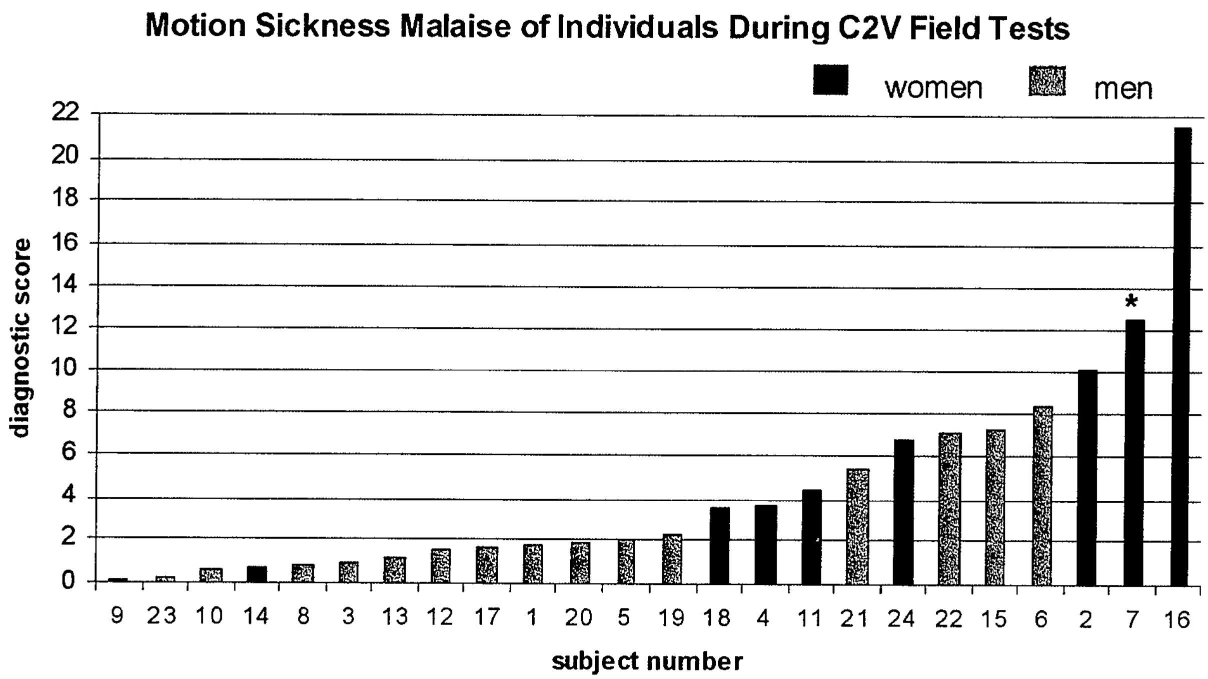
Complete Experiment Schedule and Replacement Dates

	S#	5/18	5/19	5/20	5/21	5/26	5/27	5/28	5/29	6/1	6/2	6/3	6/4	6/5	6/8	6/9	6/10	6/11	6/12	6/15	6/16	6/17	6/18	6/19	6/22	6/23	6/24	6/25	6/26
		P - 1	P - 2	P - 3	P - 4	D - 1	D - 2	D - 3	D - 4	D - 5	D - 6	D - 7	D - 8	D - 9	D - 10	D - 11	D - 12	D - 13	D - 14	D - 15	D - 16	D - 17	D - 18	D - 19	D - 20	D - 21	D - 22	D - 23	D - 24
AM	1	V3S4	\	V1S4		V1S1		V3S1		V3S2		V1S2		V1S3		V3S3		V3S4	\	V3S4		V2S1		V2S2		V2S3		V2S4	
	2	V3S3	l	V1S3		V1S2		V3S2		V3S1		V1S1		V1S4		V3S4		V3S3	D15	V3S3		V2S2		V2S1		V2S4		V2S3	
	3	V3S2	D13	V1S2		V1S3		V3S3		V3S4		V1S4		V1S1		V3S1		V3S2	l	V3S2		V2S3		V2S4		V2S1		V2S2	
	4	V3S1	l	V1S1		V1S4		V3S4		V3S3		V1S3		V1S2		V3S2		V3S1	/	V3S1		V2S4		V2S3		V2S2		V2S1	
	5	V1S4	l	V3S4		V3S1		V1S1		V1S2		V3S2		V3S3		V1S3		V1S4		V2S4		V2S1		V2S2		V2S3		V2S4	
	6	V1S3	l	V3S3		V3S2		V1S2		V1S1		V3S1		V3S4		V1S4		V1S3		V2S3		V2S2		V2S1		V2S4		V2S3	
	7	V1S2	l	V3S2		V3S3		V1S3		V1S4		V3S4		V3S1		V1S1		V1S2		V2S2		V2S3		V2S4		V2S1		V2S2	
	8	V1S1	/	V3S1		V3S4		V1S4		V1S3		V3S3		V3S2		V1S2		V1S1		V2S1		V2S4		V2S3		V2S2		V2S1	
PM	9	V1S4		V3S4		V3S1		V1S1		V1S2	\	V3S2		V3S3		V1S3	/	V1S4	V1S2			V2S1		V2S2		V2S3		V2S4	
	10	V1S3		V3S3		V3S2		V1S2		V1S1	l	V3S1		V3S4		V1S4	l	V1S3	V1S1			V2S2		V2S1		V2S4		V2S3	
	11	V1S2		V3S2		V3S3		V1S3		V1S4	D14	V3S4		V3S1		V1S1	P1	V1S2	V1S4			V2S3		V2S4		V2S1		V2S2	
	12	V1S1		V3S1		V3S4		V1S4		V1S3	l	V3S3		V3S2		V1S2	l	V1S1	V1S3			V2S4		V2S3		V2S2		V2S1	
	13	V3S4		V1S4		V1S1		V3S1		V3S2	l	V1S2	\	V1S3		V3S3	l	V3S4	V3S2	V1S2		V2S1		V2S2		V2S3		V2S4	
	14	V3S3		V1S3		V1S2		V3S2		V3S1	l	V1S1	D15	V1S4		V3S4	l	V3S3	V3S1	V1S1		V2S2		V2S1		V2S4		V2S3	
	15	V3S2		V1S2		V1S3		V3S3		V3S4	l	V1S4	l	V1S1		V3S1	l	V3S2	V3S4	V1S4		V2S3		V2S4		V2S1		V2S2	
	16	V3S1		V1S1		V1S4		V3S4		V3S3	/	V1S3	/	V1S2		V3S2	\	V3S1	V3S3	V1S3		V2S4		V2S3		V2S2		V2S1	
AM	17		V1S4		V3S4		V3S1		V1S1		V1S2		V3S2		V3S3		V1S3	\	V1S3		V1S3		V2S1		V2S2		V2S3		V2S4
	18		V1S3		V3S3		V3S2		V1S2		V1S1		V3S1		V3S4		V1S4	D14	V1S4		V1S4		V2S2		V2S1		V2S4		V2S3
	19		V1S2		V3S2		V3S3		V1S3		V1S4		V3S4		V3S1		V1S1	l	V1S1		V1S1		V2S3		V2S4		V2S1		V2S2
	20		V1S1		V3S1		V3S4		V1S4		V1S3		V3S3		V3S2		V1S2	/	V1S2		V1S2		V2S4		V2S3		V2S2		V2S1
	21		V3S4		V1S4		V1S1		V3S1		V3S2		V1S2		V1S3	\	V3S3		V3S3		V2S4		V1S3		V2S2		V2S3		V2S4
	22		V3S3		V1S3		V1S2		V3S2		V3S1		V1S1		V1S4	D18	V3S4		V3S4		V2S3		V1S4		V2S1		V2S4		V2S3
	23		V3S2		V1S2		V1S3		V3S3		V3S4		V1S4		V1S1	l	V3S1		V3S1		V2S2		V1S1		V2S4		V2S1		V2S2
	24		V3S1		V1S1		V1S4		V3S4		V3S3		V1S3		V1S2	/	V3S2		V3S2		V2S1		V1S2		V2S3		V2S2		V2S1

RESULTS

Motion Sickness

All 24 soldiers reported symptoms of motion sickness to some degree during C2V operations, with 55% reporting symptoms that ranged from moderate to severe malaise (>2 points). Figure 8 shows the mean diagnostic score of all field tests for each soldier.



*Subject 7 withdrew from the experiment.

Figure 8. Mean malaise scores of each soldier, averaged across vehicles, seats, and conditions.

Motion sickness composite scores (based on a cumulative total of all symptoms) were calculated from the field test data providing 36 scores for each subject (3 vehicles x 4 seats x 3 conditions, i.e., park, move, and short halt). A Friedman repeated measures analysis of variance (ANOVA) of all dependent measures was highly significant (chi square = 133.87, $p < 1.74$ E-10). Wilcoxon paired tests revealed no significant differences between vehicles for the park, move, or short-halt conditions. However, there was a significant increase in motion sickness within vehicles when conditions changed from park to move (oblique, $p < .0002$; perpendicular, $p < .002$; and 4-forward, $p < .00009$), and from park to short halt (oblique, $p < .0003$; perpendicular, $p < .005$; 4-forward, $p < .00007$). There was no significant difference between move and short-halt conditions for the perpendicular and 4-forward vehicles. However, in the oblique vehicle, symptoms were significantly higher during short halt than move ($p < .03$).

Figure 9 shows the mean symptom scores of subjects in each seat and vehicle across the three field test conditions. Although motion sickness scores were higher in Vehicle 1, Seat 3, there was no significant difference between Seat 3 in any of the vehicles during the move condition. Further, there was no significant difference between Seat 3 and any of the other seats in the oblique vehicle during the move or short-halt conditions. Note, however, that during the short-halt condition, motion sickness levels were significantly higher in the oblique vehicle Seat 3 than in the 4-forward vehicle Seat 3 ($p < .05$). Of all seat comparisons, this was the only one found to be significant, but this has little practical value as Seat 3 was in a different location within the 4-forward relative to the other two vehicles.

Figure 10 shows the specific symptoms ranked by the percentage of subjects reporting them in each of the three vehicles. Drowsiness was reported most frequently (60% to 70% of the subjects). There were 37 documented observations by data collectors of 16 subjects sleeping during field tests, (i.e., napping between scheduled tasks). The next most often reported symptom was headache (40% to 56% of subjects), followed by the sensation of increased warmth (40% to 45%) and nausea (35% to 42%). Less severe symptoms of stomach discomfort (epigastric discomfort [ED]) and unusual awareness of stomach sensations (epigastric awareness [EA]) were reported by at least 20% of the soldiers. Although frank vomiting episodes occurred in 15% of the soldiers, they tended to occur repeatedly in the same individuals.

Figure 11 shows the percentage of subjects reporting drowsiness in each seat and vehicle across conditions. Inspection of this graph shows that drowsiness increased two to three-fold in most of the seats as the vehicle condition changed from park to move and short halt. Further, drowsiness observed during the park condition was unrelated to the number of hours' sleep obtained on the nights before field tests (Spearman ρ, r = 0.18). Circadian rhythm effects on drowsiness were examined by comparing mean drowsiness scores in the park condition of subjects tested in the morning to those tested in the afternoon. There was no significant difference between the two groups (Mann Whitney U = 62.5, p = ns).

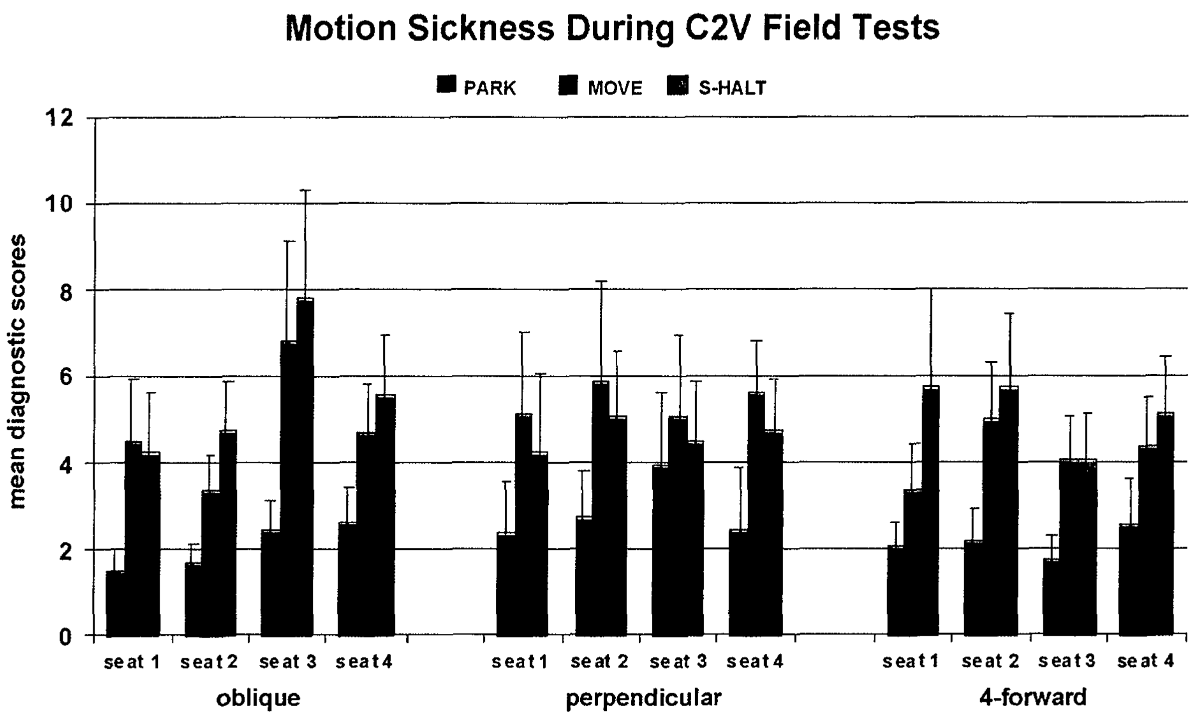


Figure 9. Average malaise scores in each vehicle and seat during park, move, and short-halt conditions (n=23 subjects).

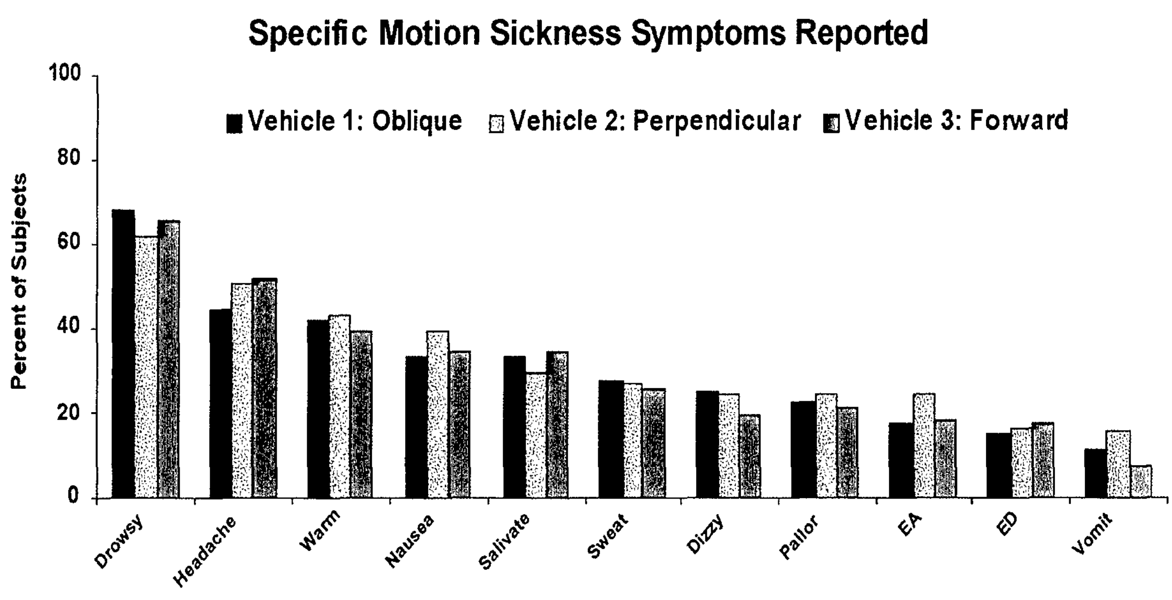


Figure 10. Percentage of subjects reporting specific symptoms during C2V field operations.

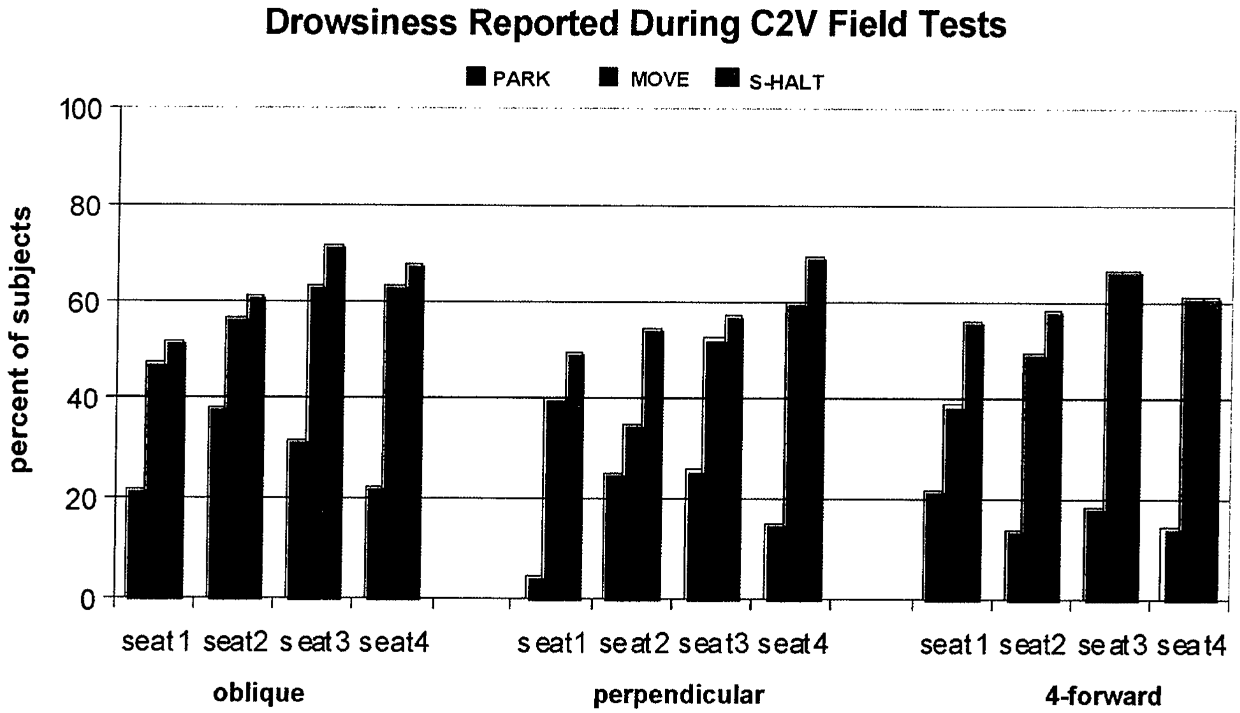


Figure 11. Percentage of subjects reporting drowsiness in each seat and vehicle across conditions in the field tests.

Performance

During the initial eight training trials in the classroom, all performance subtest variables of interest (accuracy and latency) stabilized after one training trial with respect to subtest variance (Cochran's test for homoscedasticity of variance). All subtest variables stabilized after five sessions with respect to subtest mean (linear regression slope test, $p > 0.05$) except for the choice reaction time mean adjusted latency, which required six sessions for stabilization. Some of the subjects reported for training sessions with significant prior night sleep loss. Attention lapses in the reaction time or grammatical reasoning subtests in these subjects were noted by the experimenter before knowledge of their sleep loss since such lapses are a common symptom of the effects of sleep loss on performance (Webb, 1968).

Raw performance scores were converted to z-scores for subsequent analyses. Z-scores were calculated for each subject by first calculating the mean and standard deviations from all data (training, field tests, and post-test scores). Then the mean was subtracted from each field test score and divided by the standard deviation. Missing data were replaced by interpolated means.

A measure of composite performance was obtained by averaging z-scores across the seven subtests for each vehicle, seat, and condition. Table 4 shows the summary results from ANOVAs (3 vehicles x 4 seats x 3 conditions) of performance z-scores for each subtest.

The main effect for vehicle (averaged over seats and conditions) was significant for MANIKIN, CODSUB, and REACT3. The main effect for seats (averaged over conditions and vehicles) was significant for COMPOSITE, NPTAP, and PHTAP. The main effect for condition (averaged over vehicles and seats) was highly significant for all subtests except PATRNC, which was not significant for any main effects or interactions. However, sources of variance of most interest to the question of performance effects in the different vehicle configurations were the Vehicle x Condition and Seat x Condition interactions. The Vehicle x Condition interaction was significant for only three of the seven subtests (NPTAP, MANIKIN, REASON) and for the COMPOSITE. Table 5 shows the results of *post hoc* comparisons (Tukey, 1977) for these subtests.

In Vehicle 1 (oblique), COMPOSITE performance and only NPTAP showed a significant deterioration from the park to move and short-halt conditions, with no significant change from move to short halt. The performance decrement for mean COMPOSITE may have also been influenced by other subtest scores, but for these subtests, the Vehicle x Condition interactions were not significant.

In Vehicle 2 (perpendicular), there were highly significant decrements from park to move for COMPOSITE, NPTAP, MANIKIN, and REASON, with a further decrement from park to short halt in the COMPOSITE score. However, comparisons of the move to short-halt conditions showed significant improvements for COMPOSITE, NPTAP, and REASON. These results may be related to the greater number of performance batteries (i.e., practice effects) preceding tests in the perpendicular vehicle that was added 19 days after the start of this experiment. Figure 12 depicts percent changes in performance subtests (not z-scores) for all vehicles, seats, and conditions. The figure shows that there were higher scores for these subtests within the perpendicular vehicle while in the park condition relative to the other two vehicles, and MANIKIN clearly shows higher scores in all conditions for this vehicle. Despite a possible vehicle order effect, significant performance decrements were still observed in all subtests for this vehicle in response to the move condition (and to a lesser degree, during short halt), which were apparently unaffected by practice. A notable exception to the idea that practice led to improvements in performance can be seen in the data of REACT3, which improved only 1.4% from training to post-field tests. For this subtest, there were greater decrements in all conditions, including park, than were observed in either the oblique or 4-forward vehicles. Again, despite the late entry of this vehicle in the experiment, results indicate that the perpendicular vehicle showed the greatest negative impact on overall performance.

Table 4

ANOVA Results of Performance Subtests

Source	**df**	**COMPOSITE** F	p<	**NPTAP** F	p<	**MANIKIN** F	p<	**REASON** F	p<	**CODSUB** F	p<	**PHTAP** F	p<	**PATRNC** F	p<	**REACT3** F	p<
Vehicle	2,44		ns		ns	7.09,	0.002		ns	8.43	0.001		ns		ns	57.9	3.01E-12
Seat	3,66	3.67,	0.03	4.90,	0.007		ns		ns		ns	10.84	0.00003		ns		ns
Condition	2,44	44.48.	6.89E-11	29.42	2.29E-08	7.23	0.003	18.22	2.00E-06	20.53,	0.00001	32.73	3.95E-09		ns	11.84	0.0001
Veh. x Seat	6,132		ns	4.06	0.002		ns		ns		ns		ns		ns		ns
Veh. x Cond.	4,88	4.87	0.005	4.95,	0.003	3.74	0.01	2.74	0.04		ns		ns		ns		ns
Seat x Cond.	6,132		ns		ns		ns		ns		ns	2.54	0.03		ns		ns
V x S x C	12,264		ns		ns		ns		ns		ns	2.29	0.03		ns		ns

COMPOSITE = mean of all subtests; **NPTAP** = non-preferred hand tapping; **MANIKIN** = spatial transformation; **REASON** = grammatical reasoning; **CODSUB** = code substitution; **PHTAP** = preferred hand tapping; **PATRNC** = pattern comparison; **REACT3** = three-choice reaction time.

Table 5

Tukey's Honestly Significant Difference (HSD) Multiple Comparisons: Interaction of Vehicle x Condition

	Oblique	Perpendicular	4-forward
		Park versus move	
COMPOSITE	$p < 4.05E\text{-}06$	$p < 2.26E\text{-}06$	ns
NPTAP	$p < 2.32E\text{-}06$	$p < 2.26E\text{-}06$	ns
MANIKIN	ns	$p < .002$	ns
REASON	ns	$p < .00008$	ns
		Park versus short halt	
COMPOSITE	$p < .004$	$p < .03$	ns
NPTAP	$p < .0001$	ns	ns
MANIKIN	ns	ns	ns
REASON	ns	ns	ns
		Move versus short halt	
COMPOSITE	ns	$p < .002$	ns
NPTAP	ns	$p < .02$	ns
MANIKIN	ns	ns	ns
REASON	ns	$p < .003$	ns

In Vehicle 3 (4-forward), there were no significant changes across any of the conditions for COMPOSITE or for the three subtests, NPTAP, MANIKIN, and REASON. This result does not necessarily indicate that the 4-forward configuration has less impact on performance than the oblique vehicle does. A direct comparison of these two vehicles (see Table 5) shows that they differ for only one subtest (NPTAP) and the COMPOSITE.

The Seat x Condition interaction was only significant for PHTAP. *Post hoc* tests showed PHTAP was significantly degraded in all seats ($p < .02$ or lower) except for Seat 4, the one in the front of the vehicle and the one that faced forward in all vehicles. Further, only PHTAP showed a significant Vehicle x Seats x Condition interaction. *Post hoc* tests showed that only in Seat 1 (farthest rear) in the oblique vehicle was this task significantly degraded and only during the short-halt condition ($p < .01$ or lower).

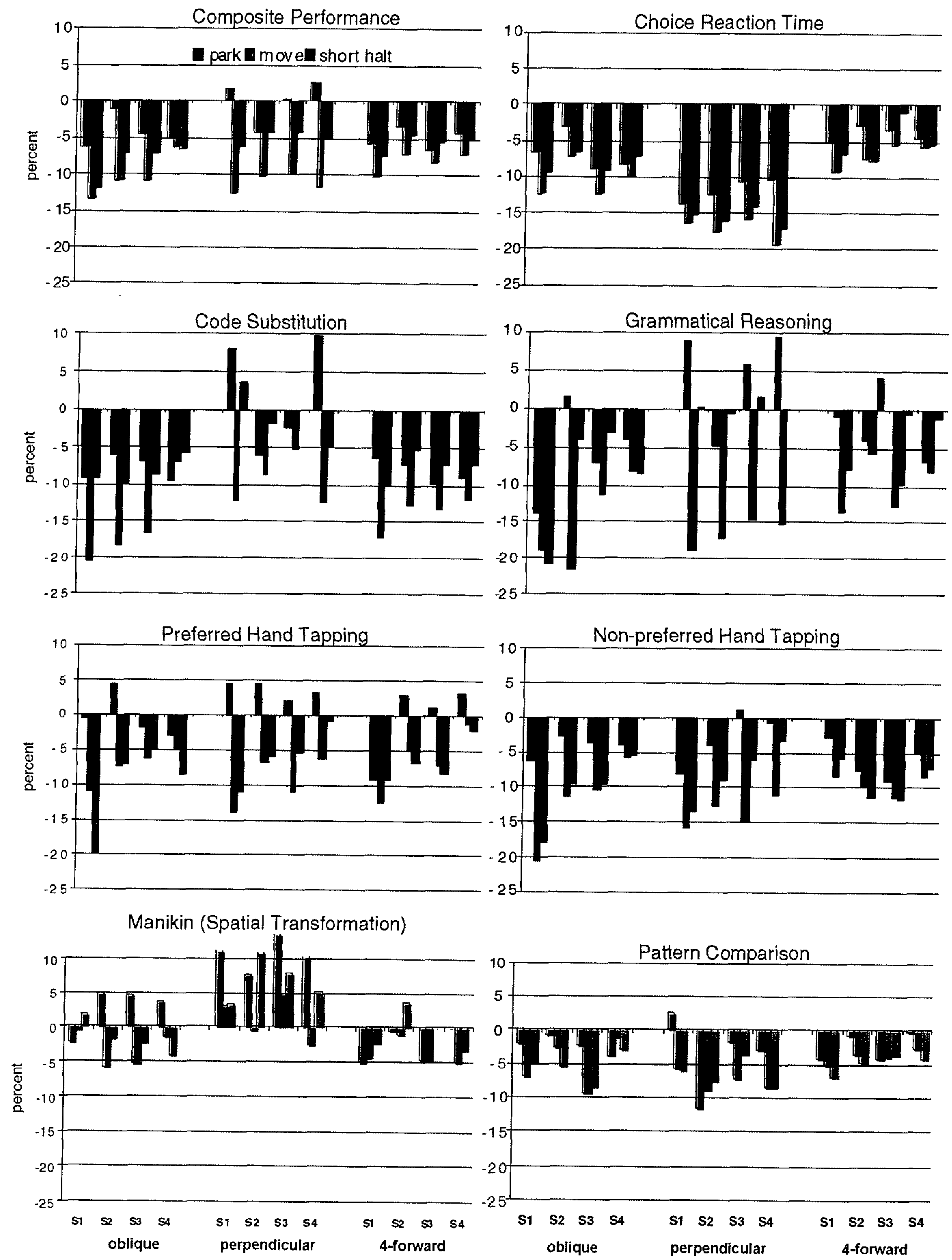


Figure 12. Performance percentages expressed as changes from baseline for all subtests. (X-axis labels [S1, S2, S3, S4] represent Seats 1 to 4.)

A method for describing the degree of performance decrement observed in this experiment was based on a percent change from baseline scores (see Figure 12). Baseline scores for each subtest for each subject were computed as the average of the last training session (Trial 8) performed in the classroom before the start of field tests and the post-field test session conducted at the end of the experiment. All negative subtask percentage scores therefore represent a decrement from this baseline, including reaction time scores, which were converted to responses per second. Baseline scores were computed to accommodate practice effects, which modulated performance levels during the field test batteries. These practice effects occurred during the course of 31 to 86 repetitions of the performance test batteries performed by the soldiers. Because of the different number of test batteries performed in the C2V and the fact that people do not learn at the same rates (i.e., differential practice effects and learning curve trajectories), performance improvement from training Trial 8 to the post-field test day ranged from 1.4% to 43.7%. These improvements may also have been influenced by whether the subjects were rested during the post-field test. The 15 subjects who were tested within 2 hours of the last field test may have been showing cumulative effects from the C2V operational environment, while the 8 subjects tested 2 days after field tests had more time to rest.

Two methods were used for evaluating the potential operational significance of performance decrements. The first involved establishing a subject impairment criterion, which was defined as at least a 5% performance decrement (negative percent change) in at least five of the seven performance battery subtests (Turnage & Kennedy, 1992). The probability of at least five subtests exceeding this criterion is $p < .02$, based upon a Monte Carlo simulation of performance subtest changes using performance data obtained from a prior human study (DeRoshia & Greenleaf, 1993). This impairment occurred in nearly half (11 of 24) of the participating soldiers. A performance decrement of >5% was observed in 22 of the 24 subjects for at least two subtests and in more than 20 subjects for at least three subtests (see Figure 13).

The second operational impairment index involved the conversion of performance percent subtest decrements to blood alcohol level equivalency (BAL%). Data from a study of performance subtest responses to alcohol levels of 0.0 to 0.15 BAL% (Kennedy, Turnage, Wilkes, & Dunlap, 1993) were converted from number of correct responses to percent net accuracy change for each subtest common to both studies. Linear regression on percent subtest change against BAL% was then performed for BAL% of 0.0 to 0.05% and of 0.05 to 0.15%. The obtained regression coefficients were then used to convert percent decrement for each subtest in this study to BAL%. To establish the regression coefficients for the composite performance metric, the percent decrements for each subtest at each BAL% in the Kennedy study were weighted by the variance explained by linear regression (F ratio), and the weighted mean decrements were then used to establish the regression coefficients for composite performance. We established two BAL% impairment criteria for the observed performance decrements: BAL% > 0.08, which is the legal definition of impairment in most American states (Dement, 1997), and BAL% > 0.025, which is the minimum level found to be associated with significant operational performance errors (Billings, Demosthenes, White, & O'Hara, 1991).

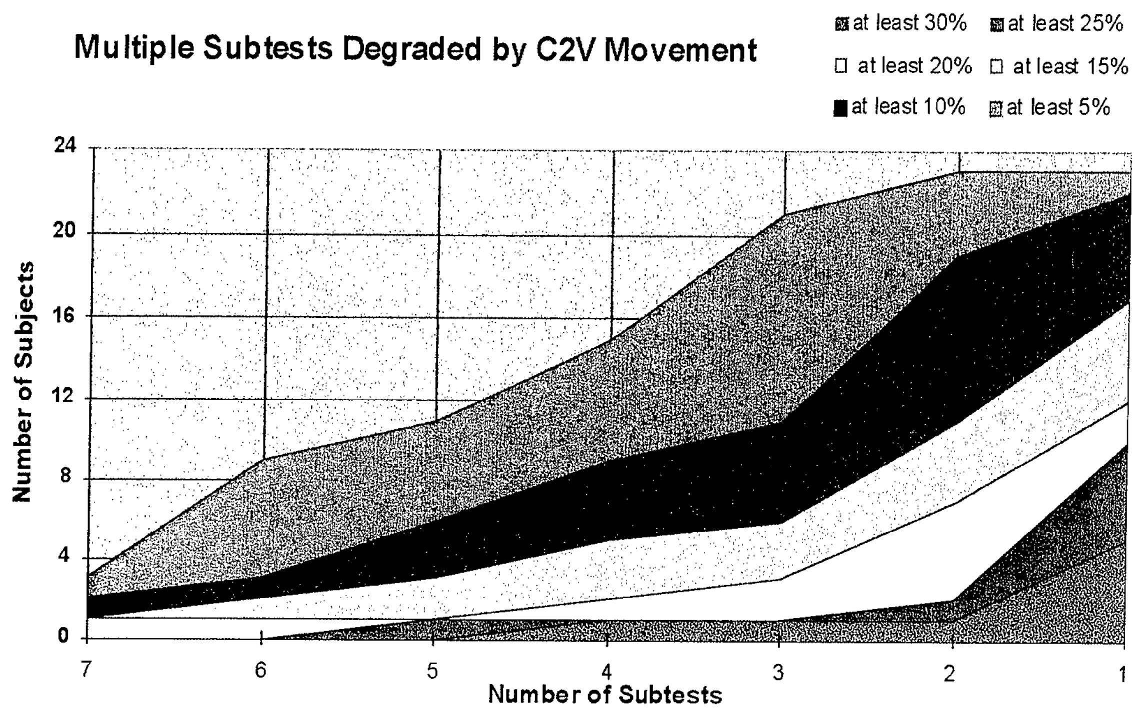


Figure 13. Number of subjects showing degraded skills of 5% to 30% in one to seven of the performance subtests.

Figure 14 shows performance-based BAL% scores of subjects during park, move, and short halt (all days). In the park condition, three subjects showed BAL% > 0.08, and four subjects exceeded the performance criterion (5/7 subtest > 5% decrement) relative to the classroom baseline. The mean decrement for all subjects in the park condition was 1.2%. In addition, the mean performance decrement in the park condition for the REACT3 test (BAL% = 0.087) exceeded the impairment criterion (BAL% = 0.08). Two of these subjects also reported severe motion sickness symptoms (i.e., nausea or vomiting) during the park condition and may have become sensitized (i.e., classical conditioning) from earlier field tests. Eight subjects showed BAL% levels of >0.08, and 19 subjects showed a BAL% of >0.025 during the move condition. Table 6 indicates the individual subjects ranked for percent performance changes and comparable BAL%.

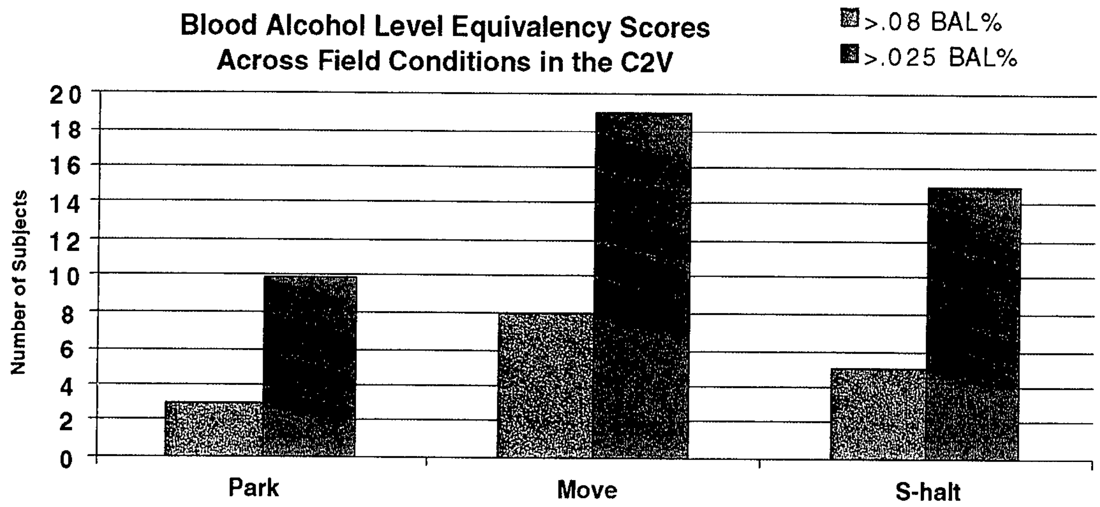


Figure 14. Number of subjects with performance-based BAL% scores of >0.08 and >0.025.

Table 6

Individuals Ranked by Percent Performance Changes and BAL%

	Subtest mean percentages				BAL% equivalence		
Subject	Park	Move	S-halt	Subject	Park	Move	S-halt
4	9.61	0.45	3.85	**4**	0.000	0.000	0.000
12	8.73	6.99	3.93	**12**	0.000	0.000	0.000
19	10.42	4.84	7.66	**19**	0.000	0.000	0.000
17	1.28	-0.79	2.46	**17**	0.000	0.008	0.000
11	5.21	-3.03	1.95	**11**	0.000	0.031	0.000
2	3.49	-3.52	3.76	**2**	0.000	0.036	0.000
5	-0.60	-3.69	-3.71	**5**	0.006	0.038	0.038
8*	-5.20	-4.06	-1.98	**8***	0.052	0.041	0.020
1	3.86	-5.08	-5.31	**1**	0.000	0.051	0.053
18	-3.29	-5.19	-5.74	**18**	0.034	0.052	0.055
9	-3.01	-5.32	-2.94	**9**	0.031	0.053	0.030
21	2.41	-6.97	-3.69	**21**	0.000	0.062	0.038
10	-2.88	-8.51	-6.18	**10**	0.029	0.071	0.058
20	-0.62	-8.81	0.52	**20**	0.006	0.073	0.000
6	5.87	-8.86	-8.53	**6**	0.000	0.073	0.071
15	-4.29	-10.53	-5.36	**15**	0.044	**0.083**	0.053
13	0.32	-11.66	-4.53	**13**	0.000	**0.089**	0.046
3	1.85	-11.98	-6.73	**3**	0.000	**0.091**	0.061
24	-5.74	-15.39	-10.54	**24**	0.055	**0.111**	**0.083**
23	-6.00	-15.64	-18.08	**23**	0.057	**0.113**	**0.127**
22	-10.13	-17.70	-11.33	**22**	**0.081**	**0.124**	**0.088**
14	-15.80	-20.89	-11.98	**14**	**0.113**	**0.143**	**0.091**
16	-20.43	-32.62	-25.24	**16**	**0.140**	**0.211**	**0.168**

*Grammatical reasoning results deleted for Subject 8 because of anomalies in his data.

Mood and Sleep

The Mood-Sleep scale scores are divided into the Activation Mood Dimension (measuring readiness to perform) and the Affective Mood Dimension (measuring self-perception of readiness. The Activation Mood Dimension (i.e., readiness to perform) indicates a state of vigor, energetic arousal, or bodily reactivity in which changes in arousal are associated with changes in energy levels. This score is a mean of four mood states: motivation, arousal, fatigue, and concentration. The Affective Mood Dimension reflects feelings or emotion associated with a mental state. This score is also a mean of four mood states: tension, elation, contentedness, and physical discomfort. Figure 15 shows the mood scores for both the activation and affective dimensions in each vehicle and seat across test conditions. Higher scores reflect more positive mood states. Mood ratings measured during the field tests provided 36 scores for each subject (3 vehicles x 4 seats x 3 conditions). Friedman ANOVAs for the activation and affective dimensions were both highly significant (chi square = 102.29, $p < 1.63\text{E-}08$, and chi square = 88.23, $p < 1.73\text{E-}06$, respectively). It is clear from inspecting Figure 15 that both mood dimensions showed a progressive deterioration across field conditions. To examine specific differences between vehicles and seats, relative to park, move, and short-halt conditions, subsequent Wilcoxon paired tests were performed. For activation scores, there were generally significant decreases ($p < .01$) from park to move and from park to short halt. The only exceptions were the rear two seats (Seats 1 and 2) in the perpendicular vehicle, which may be related to the lower initial levels observed in the park condition. For affective scores, there was again a general decline across field conditions. However, this dimension showed fewer significant changes than the activation dimension did. Scores were generally lower in the perpendicular vehicle in the park condition relative to the other two vehicles. As a result, only Seat 4 showed a significant decrease from park to short halt. In the oblique vehicle, only Seat 3 showed no significant change across conditions, while in the 4-forward vehicle, all seats showed a significant decrease ($p < .05$) when vehicles changed conditions.

Figure 16 shows each of the mood states that comprise the two mood dimensions. A separate analysis showed that mood states were significantly degraded in the vehicle in all conditions relative to the classroom pre-post field test batteries (Friedman's ANOVA, chi square = 50.4, $p < .000001$). *Post hoc* Wilcoxon paired tests showed that the activation mood dimension declined from pre-field test training to park, $p < .03$. The affective mood dimension also declined from training to park, $p < .005$.

In the present study, there were three measures of sleep: (a) the number of hours of sleep obtained on the previous night before each C2V field test, and two questions that documented the quality of sleep, (b) "trouble falling asleep," and (c) "number of waking episodes on the previous night." Figure 17 shows the average amount of sleep obtained by soldiers on the nights before C2V field tests.

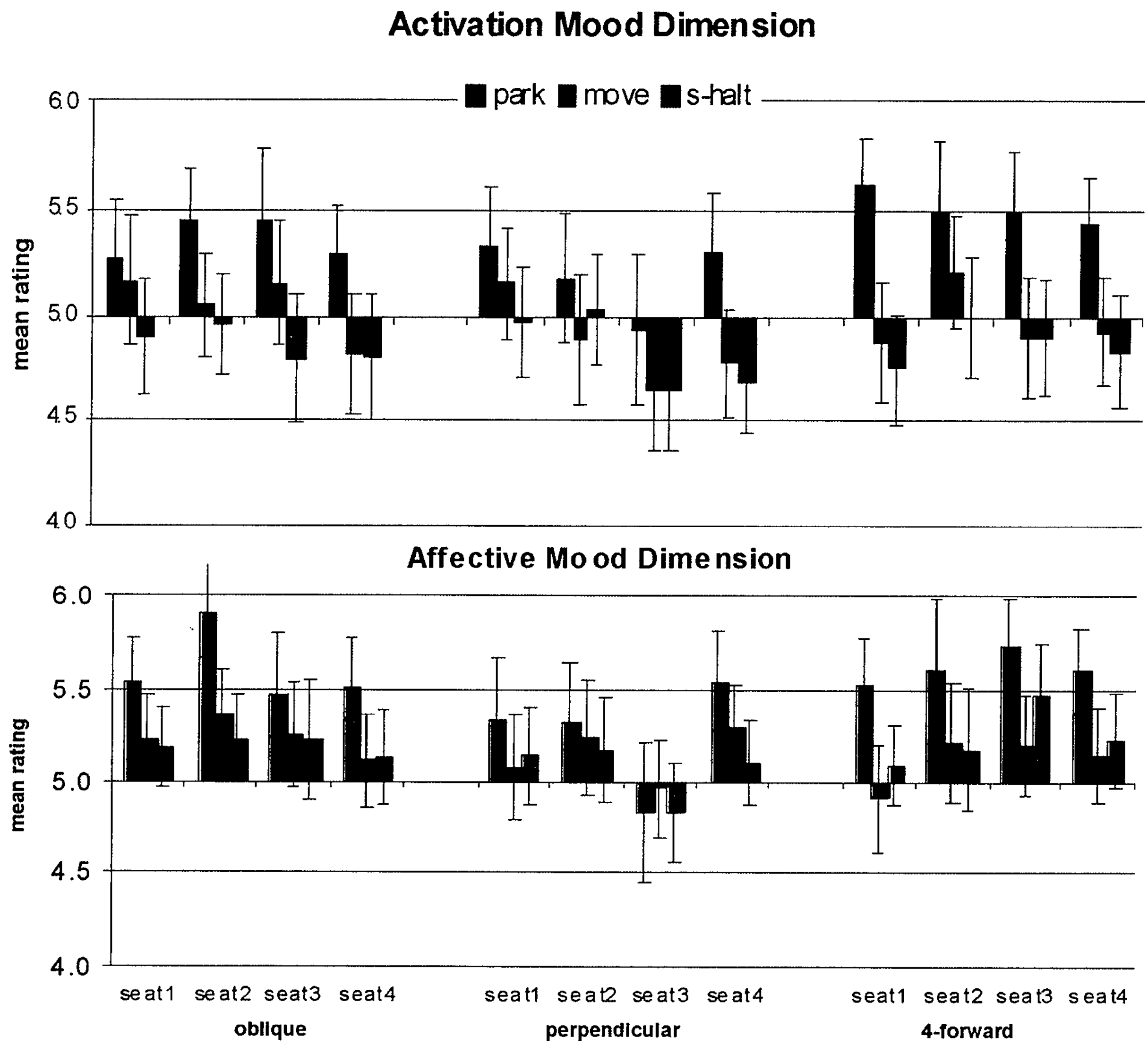


Figure 15. Activation and affective mood dimensions across field conditions (n = 23 subjects).

The mean sleep duration reported during the field exercises was 6.3 hours per night, in which subjects' self-reported sleep durations ranged from 1.5 to 16 hours. An ANOVA for sleep duration was performed to determine if this might be related to observations of performance decrements relative to specific vehicles and seats. The Vehicle x Seat interaction was significant ($F = 2.93$, $df = 6,132$, $p < .03$); however, *post hoc* comparisons did not reveal any significant differences within or between vehicles for each seat.

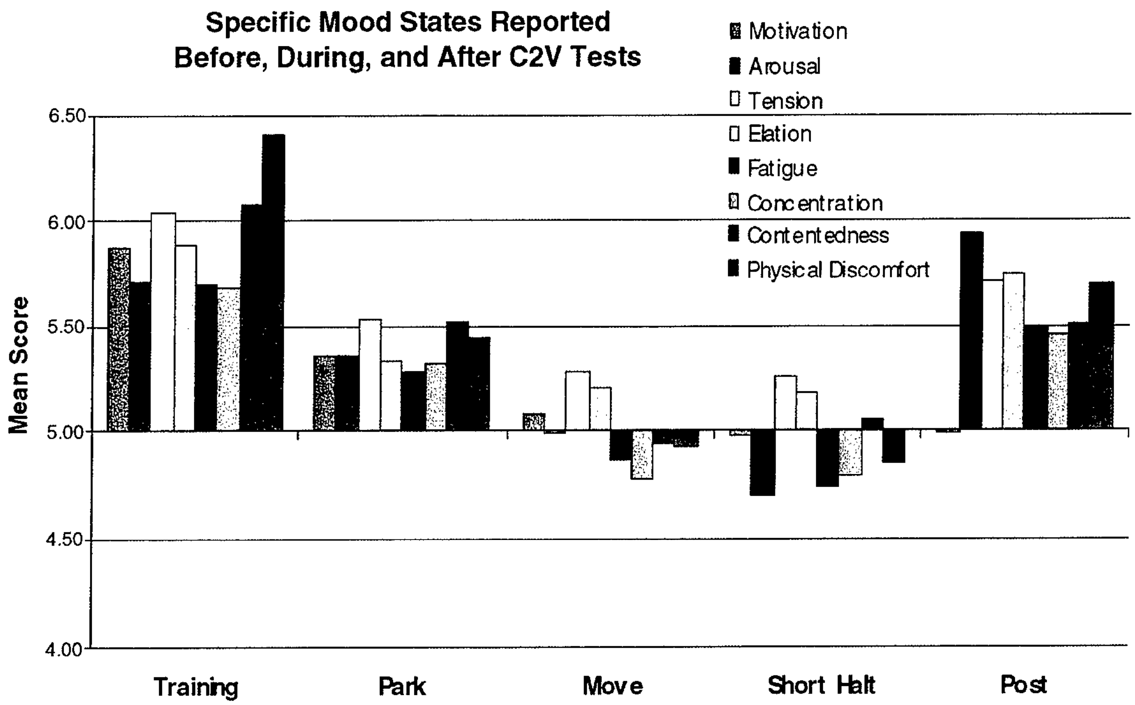


Figure 16. Mood scores of the last day of training compared to three field conditions and a classroom test at the end of the experiment.

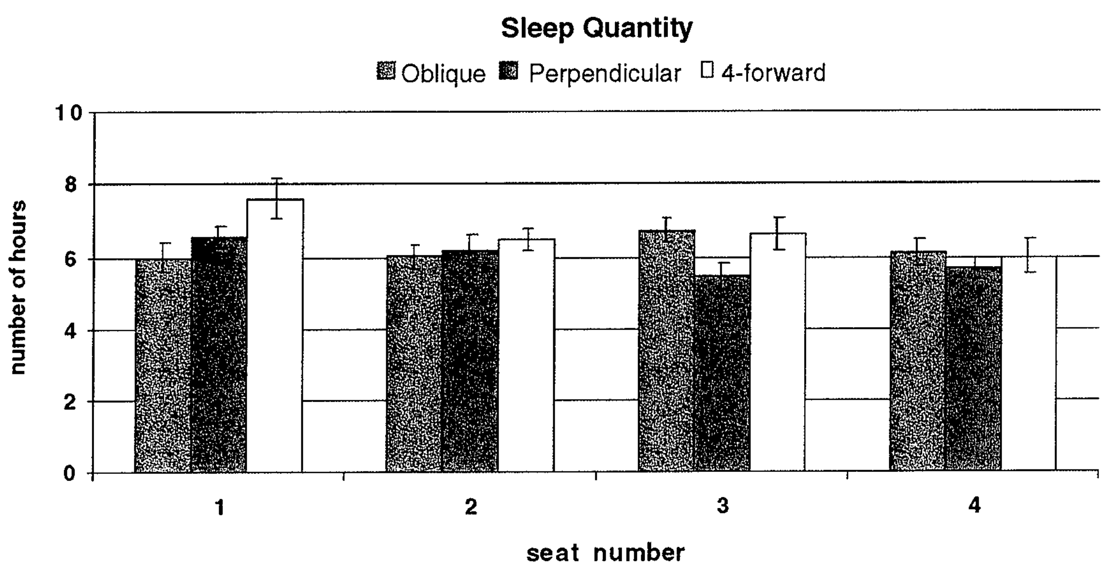


Figure 17. Sleep duration reported on the night before C2V field tests (n = 23 subjects).

Trouble falling asleep and the number of wakings reported on the previous night were analyzed, and these variables showed no significant effects for vehicles and seats. The one exception was Subject 15 who reported only 1.5 hours of sleep before his test in the perpendicular vehicle (Seat 3). On the previous night, this subject reported maximal trouble falling asleep (mood-sleep scale score = 0.0) and the maximum number of awakenings (at least six). On this test day, Subject 15 responded with the maximum performance and activation mood dimension decrements recorded from all subjects and test batteries in this study. This subject's activation mood dimension and all of its constituent scales were set at 0.0. Composite performance showed a decrement of –33.5%, equivalent to a BAL% of 0.22%. All seven subtests exhibited decrements of at least –25.6%, greatly exceeding the minimum impact of –5% for five of seven subtests known to affect operational efficiency (Turnage & Kennedy, 1992).

Physiological Responses

Physiological data during field exercises were recorded on analog cassette tapes. Data from these tapes were digitized and processed on a Concurrent© computer with custom software. These data were then edited to remove artifacts and were reduced to 15-second averages for each physiological channel. The time code recorded on analog tape was used to select specific epochs that corresponded to the C2V field test conditions of park, move, and short halt. Physiological data were collected only for the soldiers in Seat 1 and Seat 3 of each vehicle. Missing data for each subject were replaced with interpolated means before statistical analyses. Figure 18 shows the changes in physiological response means across vehicles, seats, and conditions. Summary results from the ANOVA (3 vehicles x 2 seats x 3 conditions) are described in Table 7. Sources of variance of most interest in this study were the main effect for condition and the Vehicle x Condition and Seat x Condition interactions.

The main effect for condition was significant for all four physiological response means. *Post hoc* comparisons (Tukey's HSD) of the park versus move conditions were significant for heart rate ($p < .006$) and skin temperature ($p < .003$). Comparisons for park versus short halt were significant for heart rate ($p < .01$), respiration rate ($p < .001$), and skin temperature ($p < .001$). The comparison for move versus short halt was significant only for respiration rate ($p < .004$). Inspection of Figure 18 shows that heart rate decreased significantly during the change from park to move and remained low during the short-halt conditions. Respiration rate also tended to decrease from the park condition but was only significantly lower than park during the short halt. Skin temperature, like heart rate, decreased significantly from the park to move and remained low during short halt. *Post hoc* comparisons for skin conductance level were not significant.

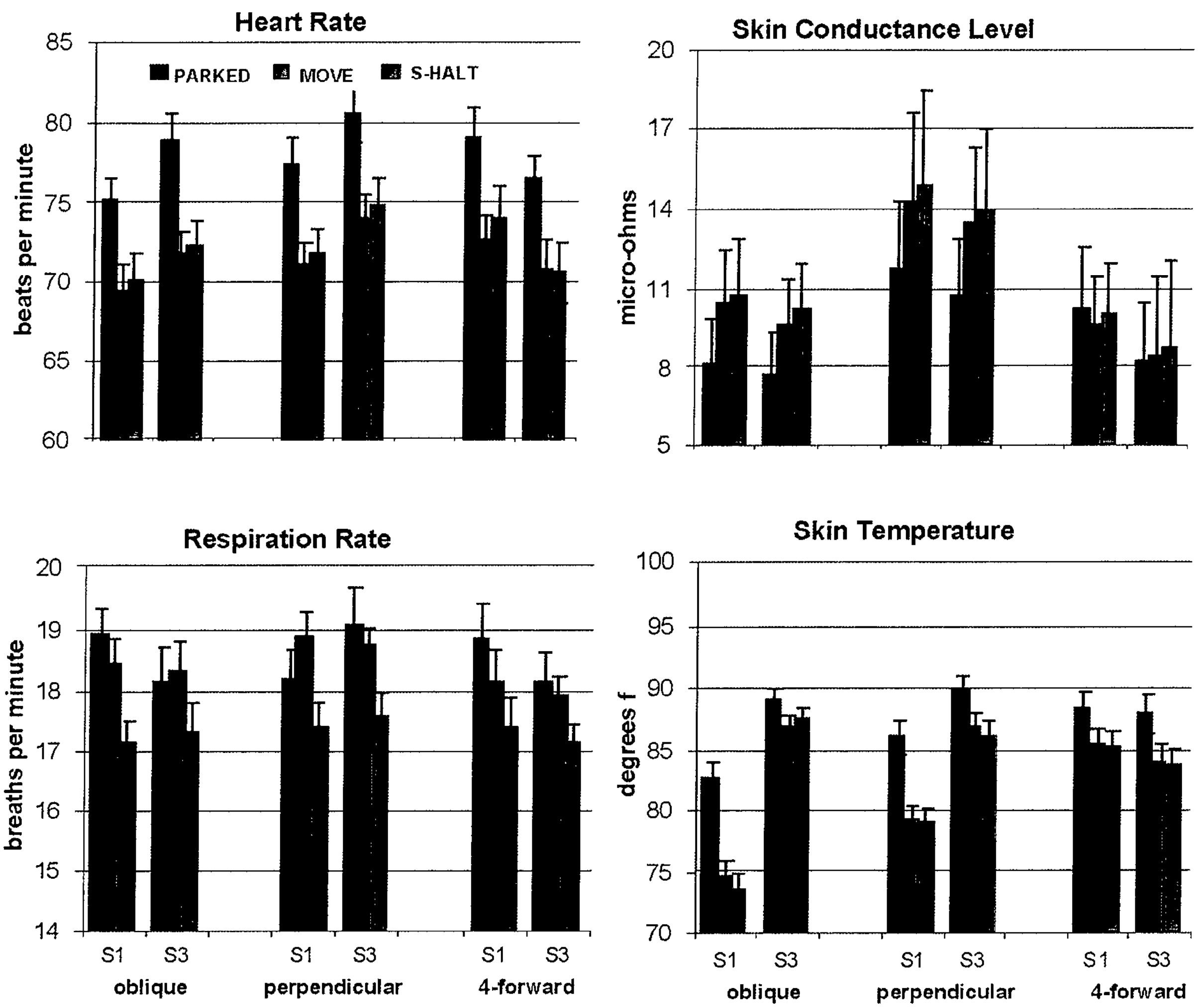


Figure 18. Means (±standard error of mean [sem]) of physiological responses during C2V field tests (n = 23 subjects).

Table 7

Summary ANOVA Results of Physiological Response Means

Source	df	Heart rate F	Heart rate p<	Respiration F	Respiration p<	Skin conductance F	Skin conductance p<	Temperature F	Temperature p<
Vehicle	2,44		ns		ns		ns	6.20	0.005
Seat	1,22		ns		ns		ns	51.95	3.18E-07
Condition	2,44	31.51	3.16E-07	17.83	0.00005	4.85	0.03	44.8	3.94E-07
Veh. x Seat	2,44	4.05	0.02		ns		ns	20.15	1.83E-06
Veh. x Cond.	4,88		ns		ns		ns		ns
Seat x Cond.	2,44		ns		ns		ns	16.73	0.00004
V x S x C	4,88		ns	3.53	0.01		ns	7.13	0.0007

The Vehicle x Condition interaction was not significant for any variable, and only skin temperature was found to be significant for the Seat x Condition interaction. *Post hoc* comparisons of this measure showed that the decrease in temperature from the park condition was greater in Seat 1 (rear) than in Seat 3 during the move ($p < .0003$) and short halt ($p < .005$).

The accelerometer transducer, which was worn on the soldier's helmet, measured velocity and force (movement in three different axes) with respect to field test conditions. This variable was used to confirm that time epochs selected corresponded to the movement profile of the C2V field tests and to determine if there were differences between seats and vehicles. An ANOVA was performed on the x-axis data only, since the other two axes (y and z) were comparable. Only the main effect for conditions was significant (F = 148.29, df = 2,44, $p < 9.99E\text{-}16$). *Post hoc* comparisons of conditions were all significant ($p < .00001$).

A second metric used to characterize physiological changes in the field conditions was the coefficient of variation (standard deviation ÷ mean of each response), which provided a measure of response variability. Figure 19 shows the coefficient of variation for each seat, vehicle, and condition.

Table 8 contains results from the ANOVA for the coefficient of variation for each physiological response. The main effect for condition was significant for all variables except skin conductance. *Post hoc* comparisons (Tukey's HSD) of the park versus move conditions were significant for respiration rate ($p < .0003$) and skin temperature ($p < .0001$). Comparisons for park versus short halt were significant for heart rate ($p < .00001$) and respiration rate ($p < .01$). The comparison for move versus short halt was significant for heart rate ($p < .0005$) and skin temperature ($p < .001$). Inspection of Figure 19 shows that variability of the heart rate response increased during the change from park to move and continued to increase during the short-halt conditions. Respiration rate variability also tended to increase from the park condition with only a slight nonsignificant decrease during short halt. Skin temperature variability similarly increased from the park to move and then decreased again during short halt. The Vehicle x Condition interaction was only significant for heart rate; however, the *post hoc* comparisons between vehicles for each condition were not significant.

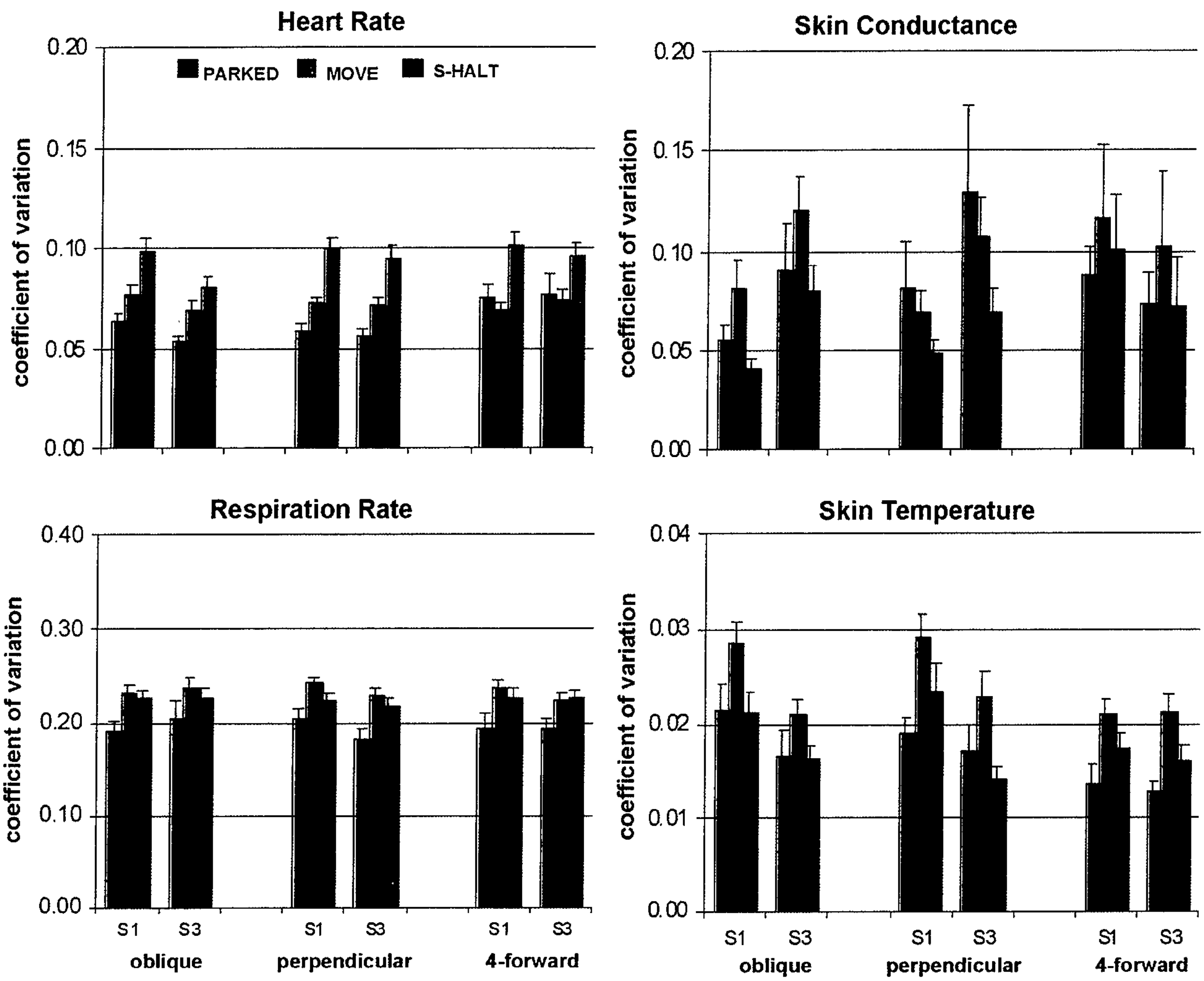


Figure 19. Physiological response variability, expressed as means of the coefficient of variation (±sem) across vehicles, seats, and conditions (n = 23 subjects).

Table 8

Summary ANOVA Results of Physiological Response Coefficient of Variation

		Heart rate		Respiration		Skin conductance		Temperature	
Source	df	F	p<	F	p<	F	p<	F	p<
Vehicle	2,44	4.20	0.03		ns		ns	5.22	0.01
Seat	1,22	11.48	0.002		ns		ns	22.44	0.0001
Condition	2,44	77.65	3.16E-10	38.42	2.17E-09		ns	21.19	4.19E-07
Veh. x Seat	2,44		ns		ns	4.58	0.02		ns
Veh. x Cond.	4,88	5.64	0.002		ns		ns		ns
Seat x Cond.	2,44		ns		ns		ns		ns
V x S x C	4,88		ns		ns		ns		ns

It is well known that physiological responses to stressful stimuli are highly idiosyncratic (i.e., some subjects show larger magnitude responses in one variable than in another) (Cowings et al., 1986; Engel, 1972; Duffy, 1972; Wenger & Cullen, 1972; Cowings, Naifeh, & Toscano, 1990; Stout, Toscano, & Cowings, 1993). Continuous physiological monitoring during the 4-hour field tests provided more information about environmental impact on a crew than was possible from measurements taken at discrete intervals. These data reflect immediate responses to changes in environmental conditions and the time course of both onset and recovery from stimulation. Figure 20 shows the physiological data of six soldiers expressed as 1-minute contiguous averages. This graph illustrates individual differences in autonomic responsivity.

The graph on the left shows the physiological responses of three soldiers during one field test with consistently high overall performance (relative to baseline) during this experiment. The graph on the right shows the data of three soldiers with consistently low overall performance. The legends show the composite performance percent change from baseline and their symptom scores (both averaged for all field conditions) for each subject on this specific test day. Subjects were ranked for overall performance (see Table 6), from most positive change from baseline to most negative change.

The subjects shown here were selected because they had consistently high or low performance scores throughout the experiment. The specific test days selected were representative of each subject's physiological response profiles throughout C2V field tests, contained complete performance, mood, and diagnostic data, and were uninterrupted by vehicle or computer malfunctions. In Figure 20, colored bars on the x-axis represent the approximate periods of the initial park (blue), move (green), and short-halt (red) conditions. It is noted that these are only approximations, as the duration of the field conditions varied from day to day. On the average, park and short-halt periods were 10 to 15 minutes, while move conditions varied from 30 to 50 minutes. Inspection of Figure 20 shows that subjects with low performance had higher heart rate levels and greater variability on all parameters than did subjects with high performance scores. It is also apparent that relatively large changes, particularly in skin temperature, occurred as field conditions changed. Subject 14, who reported only slight motion sickness symptoms during this test but whose performance was consistently low, shows physiological response patterns similar to the two other subjects with low performance and severe motion sickness. It is possible that Subject 14 may have reported symptoms incorrectly or was unaware of his or her physical reaction to these environmental changes.

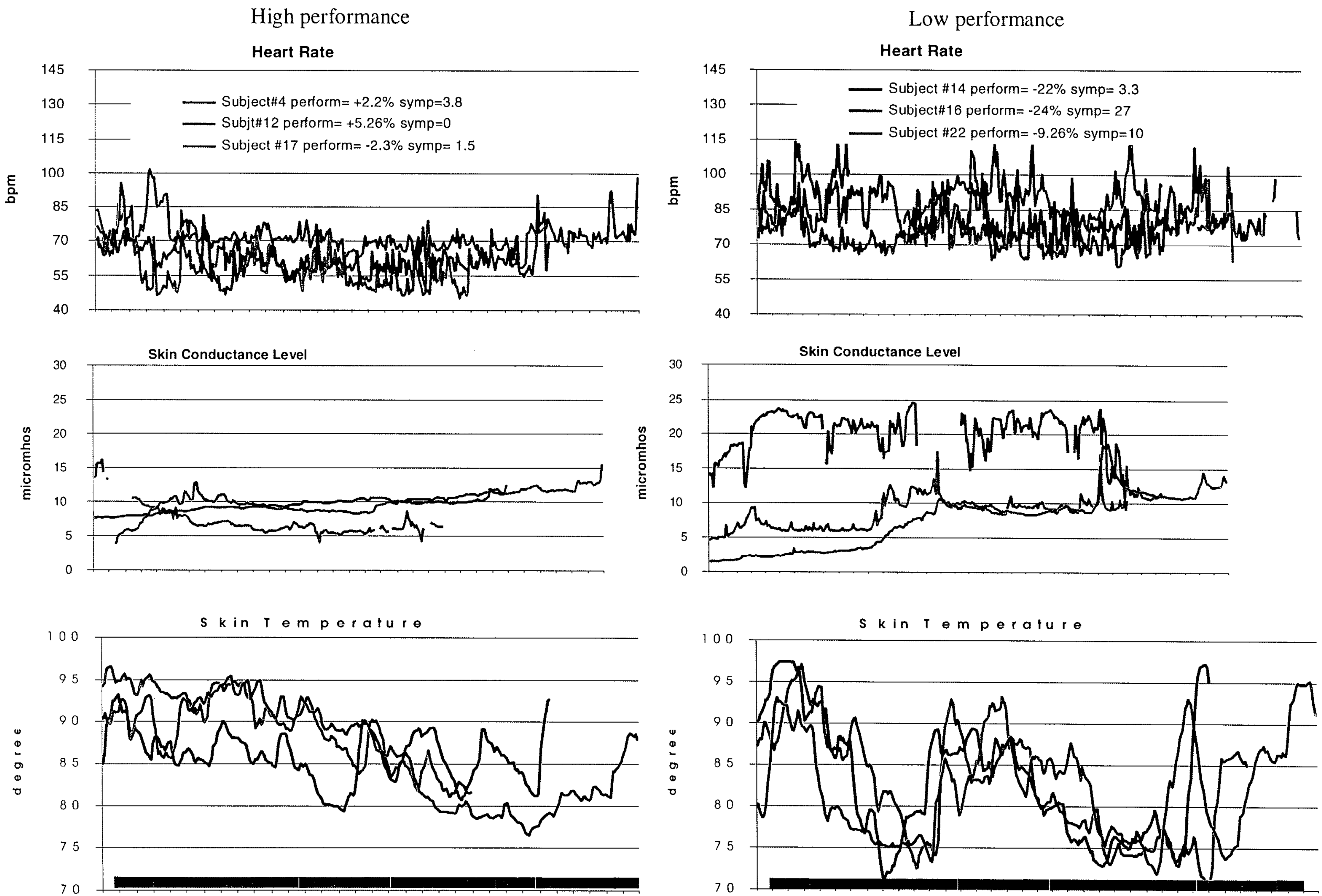


Figure 20. Physiological responses to C2V conditions. (Color bar on x-axis: park [blue], move [green], and short halt [red].)

DISCUSSION

The primary objective of this investigation was to determine the effects of C2V seat configuration during mobile field operations on incidences of motion sickness and on the ability of soldiers to perform cognitive and psychomotor tasks. The methodology of converging indicators, which included performance variables, mood state scales, symptom reports, and physiological responses, has been found to increase the accuracy of the assessment of motion sickness (Stout & Cowings, 1993). This methodology likewise proved successful in the present study for assessing the environmental impact on soldier functional state.

Motion sickness was reported by all subjects, with symptoms ranging from slight to severe, although only 15% of the participants experienced actual vomiting. Results indicated no statistical differences in mean malaise levels reported between vehicles and seats. In all cases, symptom levels increased as conditions changed from park to move and park to short halt. Drowsiness, the most frequently reported symptom in the present study, also increased significantly across the field conditions. Although some drowsiness was reported in the initial park condition, it was apparently unrelated to the previous night's sleep. Further, there was no significant difference in subjective drowsiness reports of morning and afternoon subjects. Motion can elicit the sopite syndrome, characterized by drowsiness, disinclination for physical or mental work, lethargy, reduced concentration, performance errors, frequent daytime napping, and irritability (Graybiel & Knepton, 1976). Working in moving environments may cause motion-induced fatigue, which results in twice the fatigue level as working in a stable environment (Wertheim, 1998).

Moderate levels of other motion sickness symptoms (e.g., headache, nausea, and dizziness) were also reported in the park condition before field tests began, and these reports tended to increase over the days of the experiment. One possible explanation is that subjects may have become classically conditioned by motion sickness experiences in earlier field tests, which led to increased "expectation" or "anticipation" of symptoms, even in the park condition of subsequent tests.

The diagnostic scale employed in this study was developed by a U.S. Navy research group (Graybiel et al., 1968) and has been used extensively by researchers in this field (Cowings et al., 1986; Cowings et al., 1990; Cowings & Toscano, 1982; Lentz & Guedry, 1978). It consists of easy-to-understand questions regarding specific symptoms experienced, which are later subjected to a standardized scoring method that allows comparisons across many studies and environmental conditions. It is, nonetheless, a subjective scale, which depends heavily on the accuracy of individual reports. In most research environments, the subject's report is complemented by the simultaneous observations of a trained investigator. Such symptoms as "pallor," for example, require another person to observe the subject to provide a rating. In the present study, no observers were trained in this assessment scale.

Further, the severity levels of symptoms reported may have been inconsistent for some subjects. Subject 16, for example, may have been "over-reporting" symptom severity, while Subject 14 may have been "under-reporting." Although Subject 14 reported relatively few symptoms, this subject showed a significant performance impairment during all field conditions (BAL% > 0.09) and increased physiological responsivity (i.e., response magnitude, variability, and range), which were similar to those of subjects who were highly susceptible to motion sickness (e.g., Subjects 22 and 16). Subject 16 showed both increased physiological responsivity and impaired performance (BAL% > 0.14); however, this soldier reported the highest level of malaise—nearly twice that of other participants reporting severe malaise levels. Inaccurate self-reports of malaise severity may have been the result of insufficient training during the pre-test classroom instruction period.

Despite the lack of trained observers and inconsistent reports about symptom severity by some subjects, the frequency of specific symptoms that were reported and the time course of their onset leads to the conclusion that motion sickness incidences were related to changes in the C2V test conditions. This finding is consistent with the literature about the etiology of motion sickness as a function of sensory conflict (Reason & Brand, 1975), in which symptoms occurred while subjects attempted to attend to visual displays during vehicle motion. Motion sickness has been shown to cause a large decrease in motivation, which results in a considerable deceleration of work rate and disruption of continuous work (Wertheim, 1998).

Performance subtest analyses also revealed no substantial differences between vehicles across test conditions, but there were significant degradations in performance within each vehicle when conditions changed. This finding is consistent with the results from an earlier study of the C2V (Beck & Pierce, 1996) in which performance deteriorated 10% in stationary conditions and 18% during move conditions, relative to performance in a controlled environment outside the vehicle. In the present study, performance deterioration observed during park could be the consequence of classically conditioned motion sickness symptoms or a deterioration in motivation and concentration because of distraction created by anticipation of the adverse effects of impending field tests. Calculation of BAL%, as an index of performance impairment, showed that 19 of 23 subjects were >0.025% and 8 of 23 were >0.08% during the move conditions in the C2V field tests.

Unlike the symptom scale, performance metrics provide a more objective means of assessing environmental impacts on individual functional state, with proven validity and reliability (Kennedy, Moroney, Bale, Gregoire, & Smith, 1972; Kennedy, Dunlap, Turnage, & Wilkes, 1993). The Delta performance battery employed in the present study has been shown in several studies to reliably predict military operational performance (Turnage & Kennedy, 1992; Bliss, 1990; Hodgson & Golding, 1991).

The number of performance batteries completed during the C2V field tests ranged from 31 to 86 trials, which resulted in different amounts of practice for subjects. The reliability of the percentage of calculated decrements depends on the reliability of baseline performance. Baseline, in this study, was the mean of the last training trial in the classroom and the post-field test classroom trial. These calculated decrements therefore require further validation following mathematical "de-trending" of the individual practice effects for each subtest. Despite the lack of de-trending of these data, thus far, it is noted that all subjects were found to have reached a performance plateau after only one to six trials during training in the classroom.

Performance decrements associated with different BAL% levels were established by Kennedy et al. (1993) and were employed in our own research of performance effects of promethazine (Cowings et al., 1996). However, the BAL% conversion formulas used in the 1996 study were based on a double blind design with placebo controls, which were not available in the present study. Further earlier tests were based on the Delta precursor test battery (APTS), which was presented on a different computer platform with differences in the presentation of some of the subtests. The issue of whether performance metrics or impairment criteria based upon the APTS could be extrapolated to the Delta battery was evaluated recently (Kennedy, Dunlap, Ritter, & Chavez, 1996), in which significantly higher levels of performance were found for most subtests using the PC-based Delta subtest versions. However, intra- and inter-test cross correlations were above 0.9, which indicated that the subtests in both versions were measuring the same constructs and that the scores from studies with one system can be transformed and normalized to the other by simple addition or subtraction to adjust for bias (Kennedy et al., 1996). Therefore, it was valid to convert performance decrements to BAL% scores in this study, which used the Delta battery based upon conversion formulas developed from a previous study using the APTS battery. Subject 16 in the present study showed a mean performance decrement during the move condition of -32.6%, which meets the criteria of performance decrements as calculated in earlier studies comparable to a 0.21 BAL%. It may be surmised that other subjects with high BAL% scores were also severely performance impaired. It was concluded that a substantial negative impact on cognitive and psychomotor performance was observed in this study in all three vehicles when operational conditions changed from stationary to movement conditions.

Mood states, which were derived from a subjective scale, provided another index for assessing the subject's perception of the environmental impact on his or her functional state. Both the activation and affective mood dimensions were progressively more negative as the field conditions changed. Further, these mood state responses corresponded to lower physiological response levels (i.e., decreased arousal) and degradation in performance. Overall mood states were also found to be significantly lower within the C2V than in the pre- and post-tests conducted in classrooms. As in the observed performance decrements during the park condition, degradation of mood states observed in the park condition may have resulted from classical conditioning.

Sleep data obtained from this study, concerning quantity and quality of sleep obtained on nights before C2V tests, were found to be comparable across vehicles and seats. This was an important measure relative to the goals of this study because significant performance degradation is well documented in response to sleep loss and workload fatigue (Naitoh, 1969; Holding, 1983; Dinges et al., 1997; Hockey, 1986). There was considerable variability in the amount of sleep obtained, despite instructions to subjects to avoid late-night activities or other activities that would reduce the optimum sleep-waking durations. Subjects in this experiment averaged 6.3 hours per night, which is 1.4 hours less than the average sleep duration reported for a comparable group of 20- to 29-year-olds (Tune, 1969).

According to the literature, sleep loss has a greater effect upon performance variability than upon average performance. This variability probably results from an increasing fluctuation between alertness, lowered vigilance, drowsiness, and micro-sleeps (i.e., naps), which results in loss of ability to sustain attention or its rapid degradation by repetitive sleep loss. Progressive sleep loss primarily results in an increase in the number and duration of reaction time lapses, and reductions in speed are reported far more commonly than increases in errors. The most important factor in performance decrements attributable to lapsing is task duration, which promotes the acceleration of habituation in the sleepy brain. The tasks most sensitive to sleep loss are sustained attention reaction time tasks (Dinges & Kribbs, 1991).

In the present study, sleep quantity or quality on the previous night and circadian effects were found to be unrelated to subjective drowsiness reported at the start of each C2V field test. Still, drowsiness increased across field conditions, and data collectors observed that soldiers frequently napped whenever the schedule allowed. Daytime 15- to 20-minute naps have been shown to reduce subjective sleepiness and improve task performance and self-rating of task performance (Hayashi & Hori, 1998; Takahashi, Fukuda, & Arito, 1998). Naps of 0.5 to 2 hours' duration resulted in significant improvements in reaction time, physiological activation indices, and subjective states (Taub, 1979; Taub, Tanguay, & Rosa, 1977). Mood variables such as self-reported sleepiness, fatigue, and activation consistently improve after naps (Dinges, 1989).

However, several studies have not observed improved performance after naps relative to pre-nap performance levels (Dinges, 1989). The ameliorative effect of napping upon performance depends upon length of prior sleep loss, nap length, circadian phase of the nap, elapsed time between the end of the nap, and the post-nap performance (sleep inertia) and the type of performance task (Naitoh & Angus, 1989). Sleep inertia, the time period immediately following awakening from sleep, can actually result in performance task impairment or disorientation. Sleep inertia is so pronounced during prolonged work that most investigators either do not test performance for the first 20 to 30 minutes after a nap or do not include these results of performance tests from this period in their analyses of nap benefits (Naitoh & Angus, 1989). This phenomenon lasts for at least 5 minutes in non-sleep-deprived subjects (Dinges, 1989) and is essentially dissipated within 35 minutes (Dinges, Orne, Evans, & Orne, 1981) but has been observed for as long as 2 hours' post-nap (Taub, 1979).

In a comprehensive study of sleep inertia in which recovery followed an exponential pattern requiring 0.67 hour for a return of subjective alertness and 1.2 hours for cognitive alertness, Jewett et al. (1999) found that performance could be impaired for more than 2 hours after awakening. Specific performance tests, which were shown to be negatively impacted following rapid awakening, included reaction time, visual-perceptual tasks, and various cognitive tasks (Dinges, Orne, & Orne, 1985). The documented observations of 37 incidents of 16 soldiers napping during the C2V field tests suggest that the interval between their naps and performance testing may have been less than an hour in several cases. This factor, combined with average sleep durations that were less than normal for this age group, may have contributed to the performance degradation observed in some of the soldiers.

Physiological data represent an objective index of responses to environmental stimuli. Previous research by the NASA investigators of 127 subjects showed significant differences in autonomic response levels related to motion sickness susceptibility. Highly susceptible subjects showed larger response magnitudes and variability to motion sickness stimuli than moderate or low motion sickness susceptibles (Cowings et al., 1986). Further, autonomic response patterns to motion stimuli were highly idiosyncratic, but the same subjects tended to produce stable response profiles to repeated motion sickness tests (Cowings et al., 1990; Stout et al., 1993). The 1990 study identified 12 different response patterns among 58 subjects, with subjects showing stability in one to four of these responses. Some of the subjects showed large increases (apparent activation of the sympathetic nervous system) in one response, while others produced a smaller response or no response, and some even showed a paradoxical response (decrease) to motion sickness stimulation.

In the current study, individual response patterns were not examined. However, analyses of the group responses showed significant changes in mean physiological response levels and variability (i.e., coefficient of variation) relative to the field conditions, which were comparable across vehicles and seats. The reductions in heart rate and respiration rate, for example, when conditions changed from park to move to short halt, are consistent with reduced arousal (Duffy, 1972). However, increases in skin conductance level and concomitant decreases in skin temperature (i.e., peripheral vasoconstriction) reflect sympathetic activation associated with emotional distress (Lang, 1972). These data are therefore indicative of autonomic imbalance, suggesting inadequate homeostatic controls (Wenger & Cullen, 1972).

There were large individual differences that were not apparent from the overall means. Subsequent analyses will be needed to identify specific physiological patterns of subjects participating in this study. The method for assessing individual responses to motion sickness stimuli has been used extensively in past research to identify which responses should be targeted for training subjects to reduce response variability (i.e., enhance homeostatic control). This autonomic training method, autogenic-feedback training exercise (AFTE), has been shown to increase motion sickness tolerance and improve pilot performance during emergency flying conditions (Cowings & Toscano, 1982, 1993, 1996; Cowings, Billingham, & Toscano, 1978; Cowings, 1990; Cowings, Toscano, Kamiya, Miller, & Sharp, 1988; Cowings, Toscano, Miller, & Reynoso, 1993; Cowings et al., 1994; Kellar, Folen, Cowings, Toscano, & Hisert, 1993; Toscano & Cowings, 1978, 1982, 1994).

Other factors that may have influenced the results include vibration, prior experience in this vehicle, noise, changes in ambient temperature, and the possible presence of toxic fumes. Vibration, in particular, may have affected visual acuity, in which the greatest impairment occurs at 10 to 25 Hz (Hornick, 1973). Lower frequencies (between 0.12 and 0.4 Hz) have been found to be associated with inducing motion sickness symptoms (Cowings et al., 1990; McCauley & Kennedy, 1976; Alexander, Cotzin, Hill, Ricciuti, & Wendt, 1945). The effects of vibration on manual dexterity as measured by tracking tasks showed that the greatest number of errors occurred at 5 to 11 Hz (Buckhout, 1964). The accelerometer data from the AFS-2 showed significant increases in mean amplitude during move conditions relative to park or short halt, but no significant differences were found between vehicles or seats. Vibration data obtained from accelerometers mounted at the front and rear seats of the vehicles showed that the energy in the power spectral density plots was concentrated around 5 Hz in the vertical direction (McKeever, 1998). These results suggest that vertical vibration may have been the cause of deterioration in manual dexterity tests involving the preferred and non-preferred hands.

The soldiers selected for participation in this study had relatively little previous exposure to armored tracked vehicles when this experiment began; however, each soldier had experienced a maximum of 12 C2V field tests by the end of the study (approximately 40 to 50 hours). Prior experience of performance during motion exposure may result in fewer performance decrements in a motion environment since less attention to the environment may be required (Ritmiller, 1998). Soldiers in Vehicle 2 (which was added later in the experiment) would be expected to show the effects of some adaptation to the C2V environment, to have had more opportunity to habituate to the repetitive vestibular stimulation (i.e., increased motion sickness tolerance), and to have had additional practice time leading to improved performance, than they would in the other vehicles. Although performance scores for some of the subtests were higher for this vehicle in the initial park condition, the degradation observed during move was not significantly different from those in Vehicles 1 and 3. Further, motion sickness symptom scores, mood scores, and physiological data all reflect significant negative changes during the move and short-halt conditions in Vehicle 2, which were not statistically different from the other vehicles. Further analyses need to be conducted to detect the possible occurrence of trends in the symptoms and mood state variables as a function of progressive exposure to the C2V environment to determine if adaptation occurred as a result of classical conditioning or accumulated experience in this environment.

Noise levels were not measured in this experiment. However, an evaluation of armored personnel carriers found that most tracked vehicles in the U.S. Army inventory exceeded the noise limits for verbal communication and required hearing protection to prevent damage (Shoemaker, Garinther, & Kalb, 1980). Studies have shown that noise can induce lapses in vigilance or sustained attention (Broadbent, 1953), complex mental, psychomotor, and perceptual tasks (McCormick, 1976) and can impair reaction times (Albery, 1989).

The data collectors in each vehicle recorded ambient air temperatures and relative humidity daily. Review of these data showed that despite periods when the doors were opened because of vehicle or air conditioning failures, ambient temperatures and humidity were comparable between the vehicles. Consequently, fluctuations in interior air temperatures did not account for the relatively large changes (as much as 30° Fahrenheit) measured in the skin temperature of some of the subjects when field conditions changed. Although there were some documented complaints of odors because of air conditioner failures, measures of toxic fumes in the C2V were reported to be well below hazardous levels (Brown, 1998).

CONCLUSIONS

Although other analyses of these data could be performed (e.g., correlations between individual physiological responses and specific motion sickness symptoms, de-trending performance measures to remove practice effects, gender differences, time series analyses, etc.), this report contains sufficient information needed to answer the questions posed by the Army. Further, data obtained from this experiment can be used to validate the methodology that was developed by NASA investigators to examine environmental impact on individual crew member's functional state during space flight. Studies in space of this methodology have been severely limited by the infrequency of flight opportunities and by the unavailability of flight personnel. The present study allowed NASA investigators to demonstrate the value of this assessment technology on a large sample of subjects during operational conditions and has therefore accomplished an important goal for the space agency as well as for the Army.

The methodology demonstrated in the present study may also be useful for examining impact on soldiers in other land, sea, and air vehicles in which command and control functions, similar to those of the C2V, are planned. The examination of changes in physiological responses, performance, and mood states of soldiers in these environments also provides a more comprehensive assessment of the efficacy of countermeasures for improving individual crew health and operational efficiency. Autonomic conditioning (AFTE) may be one option for mitigating negative environmental effects on soldiers and astronauts when the use of medication is untenable and when modification of the vehicle, crew tasks, or sleep schedules is not feasible.

The preponderance of evidence provided by multiple converging indicators used in this study has led to the following conclusions:

1. There was no significant difference between vehicle configurations;

2. There was negative impact on crew performance and health when subjects attended to visual computer screens while the vehicle was moving;

3. The severity of symptoms and performance degradation was not substantially reduced by intermittent short halts; and

4. Performance and mood were impaired in the vehicle during the park condition, relative to pre- and post tests conducted in a classroom facility.

REFERENCES

Albery, W.B. (1989). The effect of sustained acceleration and noise on workload in human operators. Aviation, Space, and Environmental Medicine, 60, 943-948.

Alexander, S.J., Cotzin, M., Hill, C.J., Ricciuti, E.A., & Wendt, G.R. (1945). Wesleyan university studies of motion sickness: III. The effects of various accelerations upon sickness rates. Journal of Psychology, 20, 3-8.

Beck, H.P., & Pierce, L.G. (1996). Effects of movement and intravehicle versus intervehicle communication on C2V crew performance: Limited user tests Phase III (Contract No. DAAL03-91-C0034, TCN number: 96088, Scientific Services Program). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Billings, C.E., Demosthenes, T., White, T.R., & O'hara, D.B. (1991). Effects of alcohol on pilot performance in simulated flight. Aviation, Space, and Environmental Medicine, 62, 233-235.

Bliss, J.P. (1990). Prediction of tank-gunnery simulator performance using the APTS battery. Proceedings of the Human Factors Society 34th Annual Meeting, pp. 1328-1332, Santa Monica, CA.

Broadbent, D.E. (1953). Noise, paced performance and vigilance tasks. British Journal of Psychology, 44, 295-303.

Brown, R.L. (1998). Toxic fumes of the command and control vehicle (C2V) PVT-G (TECOM Project No. 1-VS-010-C2V-009; Report No. 98-CC-300). Aberdeen Proving Ground, MD: U.S. Army Aberdeen Test Center.

Buckhout, R. (1964). Effect of whole body vibration on human performance. Human Factors, 6, 57-163.

Cowings, P.S. (1990). Autogenic-feedback training: A treatment for motion and space sickness. In G. Crampton (Ed.), Motion & Space Sickness (pp. 353-372). Boca Raton, FL: CRC Press.

Cowings, P.S., Billingham, J., & Toscano, W.B. (1977). Learned control of multiple autonomic responses to compensate for the debilitating effects of motion sickness. Therapy in Psychosomatic Medicine, 4, 318-323.[1]

Cowings, P.S., Naifeh, K.H., & Toscano, W.B. (1990). The stability of individual patterns of autonomic responses to motion sickness stimulation. Aviation, Space, and Environmental Medicine, 61, 399-405.

[1] Also in W. Luthe & F. Antonelli (Eds.), Autogenic Methods: Application and Perspectives. Rome: Luigi Pozzi S.P.A. Also in T.X. Barber et al. (Eds.), Biofeedback and Self-Control (1978). Chicago: Aldine Publishing Co.

Cowings, P.S., Stout, C.S., Toscano, W.B., Reynoso, S., DeRoshia, C., & Miller, N.E. (1996). The effects of promethazine on human performance, mood states, and motion sickness tolerance (NASA TM-110420). Ames Research Center, CA: NASA Space Life Sciences Division.

Cowings, P.S., Suter, S., Toscano, W.B., Kamiya, J., & Naifeh, K. (1986). General autonomic components of motion sickness. Psychophysiology, 23, 542-551.

Cowings, P.S., & Toscano, W.B. (1982). The relationship of motion sickness susceptibility to learned autonomic control for symptom suppression. Aviation, Space, and Environmental Medicine, 53, 570-575.

Cowings, P.S., & Toscano, W.B. (1993). Autogenic-feedback training (AFT) as a preventive method for space motion sickness: Background and experimental design (NASA TM-108780). Ames Research Center, CA: NASA Space Life Sciences Division.

Cowings, P.S., & Toscano, W.B. (1996). Monitoring and correction of human autonomic state during space flight. VII International Symposium on the Autonomic Nervous System, Montreal.

Cowings, P.S., Toscano, W.B., & DeRoshia, W. (1998). An evaluation of the frequency & severity of motion sickness incidences in personnel within the command & control vehicle (C2V) (NASA TM-112221). Ames Research Center, CA: NASA Space Life Sciences Division.

Cowings, P.S., Toscano, W.B., Kamiya, J., Miller, N.E., & Sharp, J.C. (1988). Spacelab-3 flight experiment 3AFT23: Autogenic-feedback training as a preventive method for space adaptation syndrome (Final Report, NASA TM-89412). Ames Research Center, CA: NASA Space Life Sciences Division.

Cowings, P.S., Toscano, W.B., Miller, N.E., Pickering, T.G., Shapiro, D., Stevenson, S., Maloney, S., & Knapp, J. (1994). Autogenic-feedback training: a potential treatment for orthostatic intolerance. Journal of Clinical Pharmacology, 34(6), 599-608.

Cowings, P.S., Toscano, W.B., Miller, N.E., & Reynoso, S.M. (1993). Autogenic-feedback training as a treatment for air-sickness in high performance military aircraft: Two case studies (NASA TM-108810). Ames Research Center, CA: NASA Space Life Sciences Division.

Dement, W.C. (1997). The perils of drowsy driving. New England Journal of Medicine, 337, 783-784.

DeRoshia, C.W., & Greenleaf, J.E. (1993). Performance and mood-state parameters during 30-day head down bed rest with exercise training. Aviation, Space, and Environmental Medicine, 364, 522-527.

Dinges, D.F. (1989). Napping patterns and effects in human adults. In D.F. Dinges & R.J. Broughton (Eds.), Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping (pp. 171-204). New York: Raven Press.

Dinges, D.F., & Kribbs, N.B. (1991). Performing while sleepy: Effects on experimentally induced sleepiness. In T.H. Monk (Ed.), Sleep, Sleepiness, and Performance (pp. 97-128). New York: John Wiley.

Dinges, D.F., Orne, E.C., Evans, F.J., & Orne, M.T. (1981). Performance after naps in sleep-conducive & alerting environments. In L.C. Johnson et al. (Eds.), Biological Rhythms, Sleep, and Shiftwork (pp. 539-552). New York: SP Medical and Scientific Books.

Dinges, D.F., Orne, M.T., & Orne, E.C. (1985). Assessing performance upon abrupt awakening from naps during quasi-continuous operations. Behavior Research Methods, Instruments, and Computers, 17, 37-45.

Dinges, D.F., Pack, F., Williams, K., Gilen, K.A., Powell, J.W., Ott, G.E., Aptowicz, C., & Pack, A.I. (1997). Cumulative sleepiness, mood disturbance, & psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. Sleep, 20, 267-277.

Duffy, E. (1972). Activation. In N.S. Greenfield & R.A. Sternbach (Eds.), Handbook of Psychophysiology (pp 577-622). New York: Holt, Rhinehart, and Winston, Inc.

Engel, B.T. (1972). Response Specificity. In N.S. Greenfield & R.A. Sternbach (Eds.), Handbook of Psychophysiology (pp 571-576). New York: Holt, Rhinehart, and Winston, Inc.

Graybiel, A., & Knepton, J. (1976). Sopite syndrome: A sometimes sole manifestation of motion sickness. Aviation, Space, and Environmental Medicine, 47, 873-882.

Graybiel, A., Wood, C.D., Miller, E.F., & Cramer, D.B. (1968). Diagnostic criteria for grading the severity of acute motion sickness. Aerospace Medicine, 39, 453-455.

Hayashi, M., & Hori, T. (1998). The effects of a 20-minute nap before post-lunch dip. Psychiatric Clinical Neurosciences, 52, 203-204.

Hockey, G.R.J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue and circadian rhythms. In K.E. Boff, L. Kaufman, & J.P. Thomas (Eds.), Handbook of Perception and Human Performance, II (pp. 44-1 to 44-49). New York: John Wiley.

Hodgson, M., & Golding, J.F. (1991). Psychometric evaluation of divers performing a series of heliox non-saturation dives. Aviation, Space, and Environmental Medicine, 62, 407-413.

Holding, D.H. (1983). Fatigue. In G.R.J. Hockey (Ed.), Stress and Fatigue in Human Performance (pp. 145-167). New York: John Wiley.

Hornick, R.J. (1973). Vibration. In J.F. Parker & V.R. West (Eds.), Bioastronautics Data Book (pp. 297-348). NASA SP-3006.

Jewett, M.E., Wyatt, J.K., Ritz-De Cecco, A., Khalsa, S.B., Dijk, D., & Czeisler, C.A. (1999). Time course of sleep inertia dissipation in human performance and alertness. Journal of Sleep Research, 8, 1-8.

Kellar, M.A., Folen, R.A., Cowings, P.S., Toscano. W.B., & Hisert, G.L. (1993). Autogenic-feedback training improves pilot performance during emergency flying conditions (NASA TM-104005). Ames Research Center, CA: NASA Space Life Sciences Division.[2]

Kennedy, R.S., Dunlap, W.P., Ritter, A.D., Chavez, L.M. (1996). Comparison of a performance battery implemented on different hardware and software: APTS versus DELTA. Ergonomics, 39, 1005-1016.

Kennedy, R.S., Dunlap, W.P., Turnage, J.J., & Wilkes, R.L. (1993). Human intelligence in a repeated measures setting: Commonalties of intelligence with performance. In D.K. Detterman (Ed.), Current Topics in Human Intelligence, 3, Individual Differences and Cognition (pp. 259-281). New Jersey: Ablex.

Kennedy, R.S., Jones, M.B., Dunlap, W.P., Wilkes, R.L., & Bittner, A.C. (1985). Automated portable test system (APTS): A performance assessment tool (SAE Technical Paper Series, Report No. 81775). Warrendale, PA: Society of Automotive Engineers.

Kennedy, R.S., Moroney, W.F., Bale, R.N., Gregoire, H.G., & Smith, D.G. (1972). Motion sickness symptomatology and performance decrements occasioned by hurricane penetrations in C-121, C-130, and P-3 Navy aircraft. Aerospace Medicine, 43, 1235-1239 .

Kennedy, R.S., Turnage, J.J., Wilkes, R.L., & Dunlap, W.P. (1993). Effects of alcohol on nine computerized repeated-measures tests. Ergonomics, 36, 1195-1222.

Lang, P.J. (1972). The psychophysiology of emotion. In N.S. Greenfield & R.A. Sternbach (Eds.), Handbook of Psychophysiology (pp 623-644). New York: Holt, Rhinehart, and Winston, Inc.

Lentz, J.M., & Guedry, F.E. (1978). Motion sickness susceptibility: A retrospective comparison of laboratory tests. Aviation, Space, and Environmental Medicine, 49(11), 1281-1288.

McCauley, M.E., & Kennedy, R.S. (1976). Recommended human exposure limits for very-low-frequency vibration (Report No. PMTC 76-36). Point Magu, CA: Pacific Missile Test Center.

[2] Also in Flight Safety Digest (July 1993).

McCormick, E.J. (1976). Human factors in engineering and design (4th ed.). New York: McGraw-Hill.

McKeever, J. (1998). Transportability test of the command and control vehicle (C2V) (ride quality and road shock and vibration tests) (TECOM Project No. 1-VS-010-C2V-009, Report No. 98-AIT-083). Aberdeen Proving Ground, MD: U.S. Army Aberdeen Test Center.

Naitoh, P. (1969). Sleep loss and its effects on performance (Report No. 68-3). San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

Naitoh, P., & Angus, R.G. (1989). Napping and human functioning during prolonged work. In D.F. Dinges & R.J. Broughton (Eds.), Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping (pp. 171-204). New York: Raven Press.

Reason, J.T., & Brand, J.J. (1975). Motion sickness. London, New York, San Francisco: Academic Press.

Ritmiller, L.M. (1998). Effects of vessel motion and fatigue on human performance in marine operations. Unpublished master's thesis, Simon Fraser University School of Kinesiology, Vancouver, British Columbia, Canada.

Shoemaker, C., Garinther, G., & Kalb, J. (1980). Verbal communication in tracked combat vehicles (TM-91-80). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

Stout C.S., & Cowings, P.S. (1993). Increasing accuracy in the assessment of motion sickness: A construct methodology (NASA TM-108797). Ames Research Center, CA: NASA Space Life Sciences Division.

Stout, C.S., Toscano, W.B., & Cowings, P.S. (1993). Reliability of psychophysiological responses across multiple motion sickness stimulation tests. Journal of Vestibular Research, 5(1), 25-33.

Takahashi, M., Fukuda, H., & Arito, H. (1998). Brief naps during post-lunch rest: Effects on alertness, performance, and autonomic balance. European Journal of Applied Physiology, 78, 93-98.

Taub, J.M. (1979). Effects of habitual variations in napping on psychomotor performance, memory and subjective states. International Journal Neuroscience, 9, 97-12.

Taub, J.M., Tanguay, P.E., & Rosa, R.R. (1977). Effects of afternoon naps on physiological variables, performance, and self-reported activation. Biological Psychology, 5, 19-210.

Tauson, R.A., Doss, N., Rice, D., Tyrol, D., & Davidson, D. (1995). The effect of noise and vibration (caused by moving operations) on cognitive performance in the command and control vehicle (Technical Memorandum ARL-MR-279). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Toscano, W.B., & Cowings, P.S. (1978). Transfer of learned autonomic control for symptom suppression across opposite directions of coriolis acceleration. Proceedings of the 49th Annual Scientific Meeting of the Aerospace Medical Association, pp. 132-133. New Orleans.

Toscano, W.B., & Cowings, P.S. (1982). Reducing motion sickness: autogenic-feedback training compared to an alternative cognitive task. Aviation, Space, and Environmental Medicine, 53(5), 449-453.

Toscano, W.B., & Cowings, P.S. (1994). The effects of autogenic-feedback training on motion sickness severity & heart rate variability in astronauts (NASA TM-108840). Ames Research Center, CA: NASA Space Life Sciences Division.

Tukey, J.W. (1977). Exploratory data analysis. Reading, MA: Addison-Wesley.

Tune, G.S. (1969). Sleep and wakefulness in 509 normal adults. British Journal of Medical Psychology, 60, 431-441.

Turnage, J., & Kennedy, R.S. (1992). The development and use of a computerized human performance test battery for repeated measures applications. Human Performance, 5, 265-301.

Webb, W.B. (1968). Sleep: An experimental approach. New York: MacMillen.

Wenger, M.A., & Cullen, T.D. (1972). Studies of autonomic balance in children and adults. In N.S. Greenfield & R.A. Sternbach (Eds.), Handbook of Psychophysiology (pp 535-570). New York: Holt, Rhinehart, and Winston, Inc.

Wertheim, A.H. (1998). Working in a moving environment. Ergonomics, 41, 1845-1858.

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13. ABSTRACT *(Maximum 200 words)*

The command and control vehicle (C2V) was developed to support U.S. Army tactical operation centers in heavy forces. The requirements for the C2V stipulate that it must support mobile operations and that it must support command and control (C2) from within the confines of the vehicle. However, in early testing, some human operators exhibited motion sickness during moving operations. As a result, the Human Research and Engineering Directorate of the U.S. Army Research Laboratory, in cooperation with the National Aeronautics and Space Administration's Life Sciences Division, was directed to perform a study to quantify the incidence and severity of motion sickness and any associated performance decrement. The study would discriminate between motion effects in the C2V in parked, moving, and short halt in each seat in three seat configurations.

Twenty-four soldiers were exposed to each of 12 seats (four seats in three vehicle configurations) for a 4-hour "cell." During a cell, subjects completed a motion sickness and mood scale and the Delta cognitive battery. Half the subjects were also instrumented to record physiological correlations of motion sickness. Each cell included an initial (parked) administration of the test batteries followed by two test batteries while moving and three test batteries during short halts.

Fifty-five percent of the subjects reported an average motion sickness score, indicating moderate to severe symptoms. Symptoms were not mitigated by short halts. One subject was withdrawn from the study because of severe and persistent symptoms.

Performance was significantly worse during moving operations than in parked, with a partial recovery during short halts. Performance degradation was comparable to blood alcohol equivalencies at or above 0.08% in 35% of the soldiers during movement and 22% during short halts.

There was no significant difference between seat or vehicles in any of the measurements.

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