

Effects of Command and Control Vehicle (C2V) Operational Environment on Soldier Health and Performance

Patricia S. Cowings, William B. Toscano, Charles DeRoshia, and Richard Tauson



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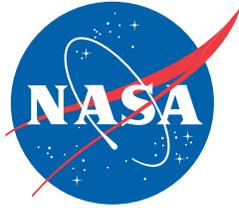
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July 1999

Acknowledgments

Bradley Fighting Vehicle Systems (BFVS)
LTC. Nathaniel H. Sledge, Jr.
Product Manager, Bradley Carrier Systems, and
MAJ. Paul Fletcher, C2V Experiment Supervisor



US Army Operational Test and Evaluation Command (OPTEC/OEC)

Gerald Garfinkel, Ph.D.
Maj. Michael Harris

US Army Test and Experimentation Command (OPTEC/TEXCOM)

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Linus Liang, West Valley Jr. College student volunteer
Ellen Chang, NASA High School Space Biology Program
Michel Yu, NASA High School Space Biology Program

This project was funded by an Interagency Agreement between the Bradley Fighting Vehicle System Program Manager and NASA Ames Research Center, Space Life Sciences Division.

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Executive Summary

Objectives: The purpose of this project was to use NASA technology to assist the US Army in the assessment of motion sickness incidences and effects on soldier performance and mood states within the Command and Control Vehicle (C2V). Specific objectives were (1) to determine if there was a significant difference between three internal configurations of the C2V and/or between seats within these vehicles; (2) to determine if there was a significant difference between the park, move, or short-halt field conditions; and (3) to validate a method of converging indicators developed by NASA to assess environmental impact of long duration spaceflight on crewmembers, using a large sample of subjects under 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. Conditions for C2V field tests were (1) an initial park, (i.e., stationary 15 to 20 minutes); (2) four moves (i.e., travel over a mixed terrain approximately 40 minutes); and (3) four short-halts (i.e., stationary 15 to 20 minutes), interspersed between moves, with one at the end of tests. Three different vehicle configurations were tested: (1) oblique, where the seat closest to the front faced forward and the remaining three seats were at a 20-degree angle from the direction of travel; (2) perpendicular, where the front seat also faced forward, but the remaining three seats were at a 90-degree angle; and (3) 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 actual vomiting, and these episodes tended to recur within the same individuals. The most frequently reported symptom was drowsiness (60–70% of subjects), followed by headache (40–56%), sensations of increased warmth unrelated to ambient air temperature (40–45%), nausea (35–42%), and uncomfortable stomach sensations approaching nausea (20%). Although there were no significant differences 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 successfully validated 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 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 were 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 posttests conducted in a classroom facility.

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The methodology demonstrated here may also be useful for examining impact on soldiers in other land, sea, and air vehicles where 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.

Introduction

The purpose of this project was to use NASA technology to assist the US Army Program Executive Office for Ground Combat and Support Systems, Product Managers Office, Bradley Fighting Vehicle System (PM-BFVS) in the assessment of motion sickness incidences within the Command and Control Vehicle (C2V). The C2V is an armored tracked vehicle, which 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 the NASA 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 conducted at the Yuma Proving Grounds (ref. 1) demonstrated that NASA's methods employed for assessment of environmental impact on soldier health and performance could be successfully conducted under operational field test conditions. Eight active duty military men (US Army) at the Yuma Proving Grounds in Arizona 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 vomiting (two episodes). 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 C2V crew. However, a number of variables (e.g., individual's sleep duration prior to the mission, 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 by the US Army Research Laboratory (ARL) (ref. 2), and at the Aberdeen Proving Grounds (ref. 3).

The objectives of the Yuma study were successfully met. The use of three converging indicators, (1) physiological monitoring, (2) subject self-reports of symptoms, and (3) measurements of performance, were 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 (1) to determine if there was a significant difference between three internal configurations of the C2V and/or between seats within these vehicles; (2) to determine if there was a significant difference between the park, move, or short-halt field conditions; and (3) to validate a method of converging indicators developed by NASA to assess environmental impact of long duration spaceflight on crewmembers, using a large sample of subjects under ground-based operational conditions.

Methods

Subjects

Twenty-four active duty military personnel (8 women and 16 men, ages 18–34) participated in this study. Subjects were medically qualified for participation in these tests following a review of their records by Army doctors to rule out any preexisting condition that might put them at risk. Subjects were briefed on the experimental procedures, and their voluntary consent was obtained prior to the start of tests. 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 the Army Research Laboratory.

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 physiological measures listed below were recorded on the AFS-2 (fig. 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):** Pregelled 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 emitter/diode 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 pregelled, self-adhesive electrodes were mounted on the volar surface of the left wrist.

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

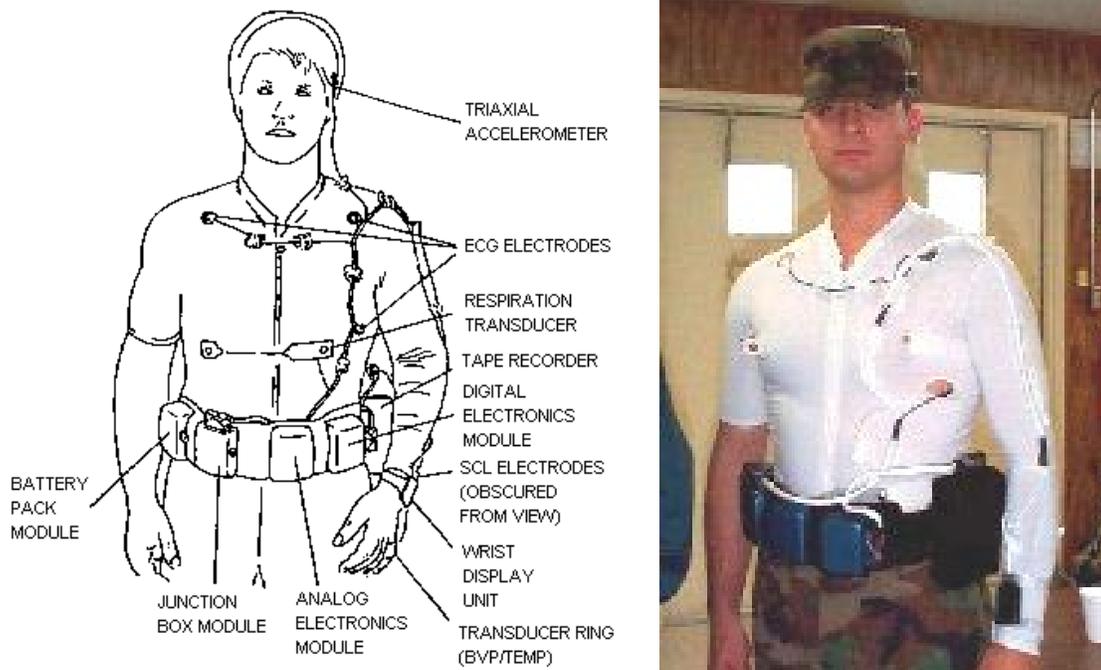


Figure 1. An illustration of the Autogenic-Feedback System-2 (AFS-2) and a photograph of a soldier wearing the AFS-2.

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 (ref. 4). The APTS was developed with emphasis on within-subject, repeated-measure designs, and has been 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 (ref. 5) and to evaluate the effects of confinement and exercise countermeasures in simulated weightlessness (bed-rest) studies (ref. 6). 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 below.

Three-choice reaction time (REACT3, 60 seconds). This test involved the presentation of a visual stimulus and the 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 and incorporates memory recall and perceptual speed (metric=accuracy).

Pattern comparison (PATRNC, 75 seconds). The 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 respond by pressing the “S” or “D” key. This is a test of integrative spatial function and may be compared to the ability of recognizing 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: (1) active versus passive wording; (2) positive versus negative wording; (3) key words such as “follows” and “precedes”; (4) order of appearance of the two symbols within the sentence; and (5) 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, which appeared on the screen to the right of the sentence. The subject responded by pressing the “T” (true) or “F” (false) keys. This test measures cognitive reasoning, logic and verbal ability and assesses an analytic 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 on 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 any symptoms they may be experiencing using computers at their workstations. A computer program allowed the subject to rate his own symptoms using a standardized diagnostic scoring procedure referred to as the Coriolis Sickness Susceptibility Index, or CSSI (refs. 7 and 8). Table 1 shows the questions presented to each test participant.

The presence or absence and/or 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?”

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, whatever level, were assigned one 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

Mood/Sleep Test (60 seconds)

Immediately following the Symptom Diagnostic Scale, a second program queried the subject on his/her current mood and alertness. A 10-point Visual-Analog Scale (VAS) (ref. 6) 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/right arrow keys. There were descriptive adjectives at each end of the slide-bar, and the subject's task was to position the cursor to enter his/her response. The higher the score, the more favorable the response. Lastly, the scale queried subjects on 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.

Vehicles

Three vehicle configurations were tested in this experiment. Vehicle 1, oblique, where seat 4 faced forward and the remaining three seats were at a 20-degree angle from the direction of travel. Vehicle 2, perpendicular, where seat 4 faced forward, but the remaining three seats were at a 90-degree angle from the direction of travel. And Vehicle 3, 4-forward, in which all four seats faced 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.

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 _____	

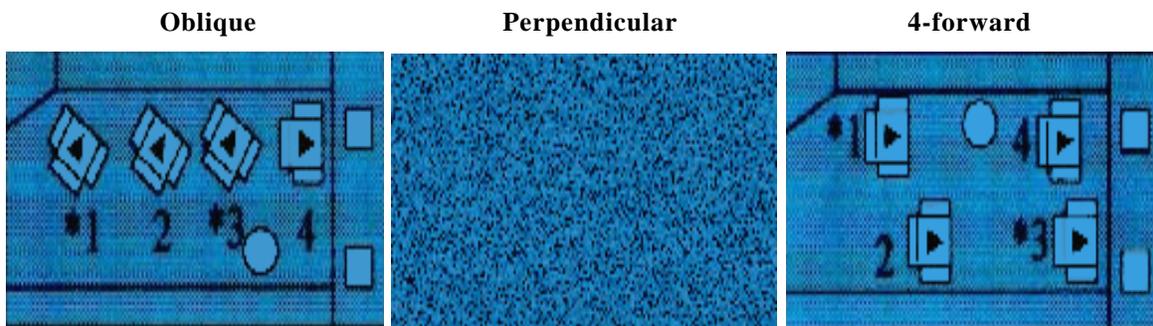


Figure 2. Seat orientations in the three vehicles.



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 (4–5 hours each day); 12 days of field tests in the C2V (4–5 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 (8 subjects).

Classroom Instruction

On the first training day, subjects received an experiment briefing from NASA and Army collaborators. During the two classroom instruction days, all soldiers were trained on the Delta test battery (4 trials per day, 8 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 (8 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 4–5 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 (ref. 2) and manual tasks (i.e., map reading, completing questions on 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 C2V crew.

In addition to training the test participants, six individuals who were designated data collectors also received instruction on experiment 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 down on daily data sheets the number of hours sleep soldiers obtained on the previous night, and assured that each soldier was assigned to the proper vehicle and seat. Further, they 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 experiment monitoring station. In this station, an assigned duty officer would call out the start times for specific tasks to be performed. Data collectors were then required to inform the soldiers within their vehicles, and 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. The photographs show soldiers receiving individual instruction on the operation of the Delta task batteries, mood and diagnostic scales. Laptop computers used for training on the CCAB tasks were on adjacent tables. The Figure 5 photographs show 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



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

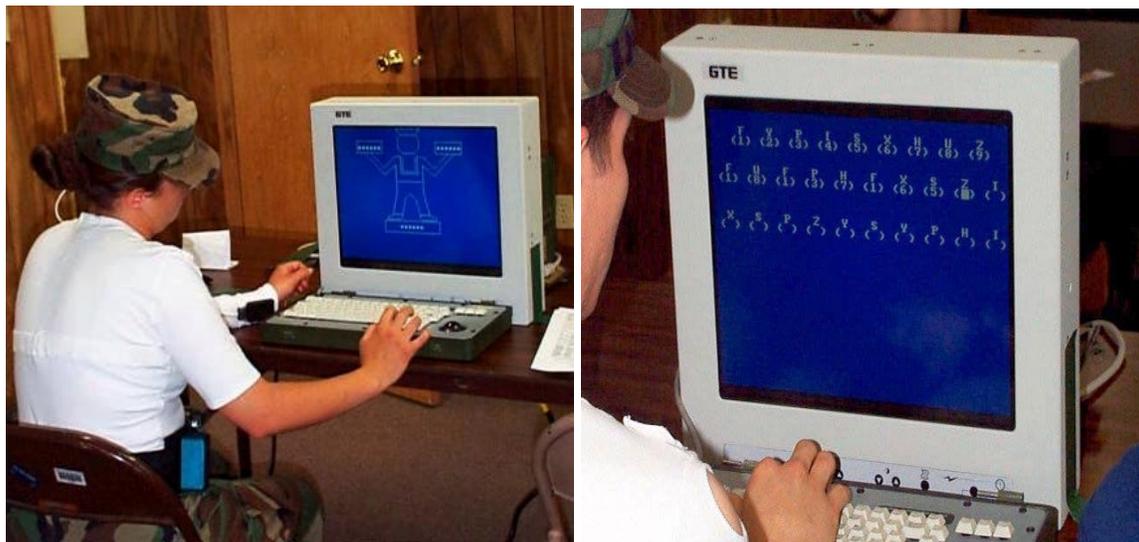


Figure 5. Soldiers performing the Manikin (left) and Code Substitution subtests (right).



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

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 a different seat in the vehicle. Figure 7 shows the scheduled activities on field tests days and the distribution of tasks performed by subjects during each 4-hour test. Following an initial “park” condition of 15–20 minutes, where 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 stationary for 15 to 20 minutes) including one short-halt at the end of the field tests. Physiological data were collected only 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 on each subject as well as test schedule changes were sent to NASA and university collaborators after the completion of each test day.

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.

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 four 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 1–8 and 17–24 were always tested in the morning, between 8:00 a.m. and 12:00 p.m., while subjects 9–16 were tested in the afternoon from 13:00 to 17:00 p.m.. All subjects were tested on alternate days, allowing one day of rest between C2V field tests. On alternate days throughout the experiment, tests were conducted in the morning only (subjects 17–24), allowing time for vehicle maintenance and repair in the afternoon.

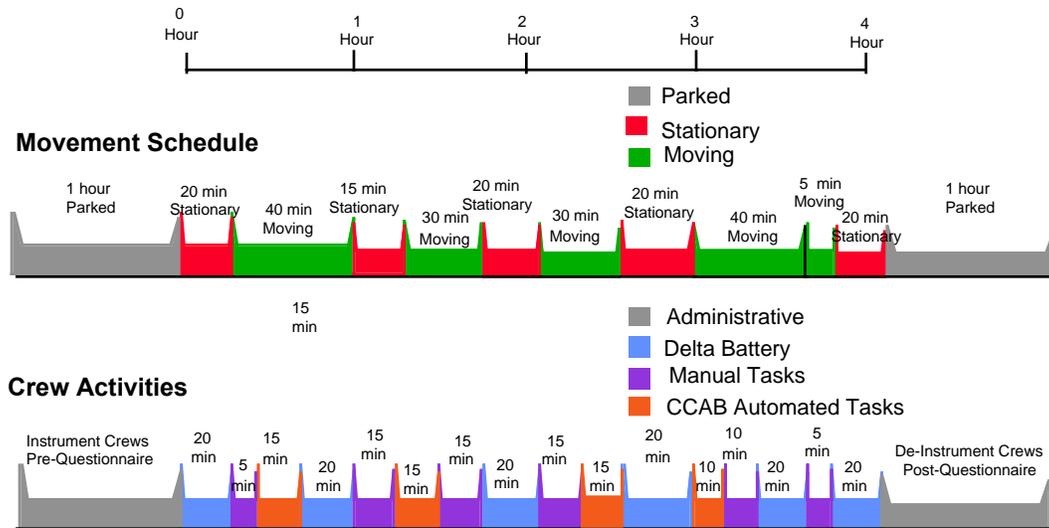


Figure 7. CV2 field tests conducted over a 4-hour period.

The yellow areas in table 3 indicate which subjects wore the AFS-2 ambulatory monitoring system, and the vehicle and seat assignments for all subjects. The gray areas represent days when field operations were canceled and replacement tests rescheduled. There were several field tests not replaced due to 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.

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.

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, $p < 1.74E-10$). 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, $p < 0.0002$; perpendicular, $p < 0.002$; and 4-forward, $p < 0.00009$), and from park to short halt (oblique, $p < 0.0003$; perpendicular, $p < 0.005$; 4-forward, $p < 0.00007$). 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 ($p < 0.03$).

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. It should be noted, 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 ($p < 0.05$). 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 (60–70% 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 (40–56% of subjects) followed by the sensation of increased warmth (40–45%) and nausea (35–42%). 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 actual vomiting episodes occurred in 15% of the soldiers, it tended to occur repeatedly in the same individuals.

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	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	V3S2	V2S3		V2S4		V2S1		V2S2						
	4	V3S1	V1S1		V1S4		V3S4		V3S3		V1S3		V1S2		V3S2		V3S1 /	V3S1	V2S4		V2S3		V2S2		V2S1						
	5	V1S4	V3S4		V3S1		V1S1		V1S2		V3S2		V3S3		V1S3		V1S4		V2S4		V2S1		V2S2		V2S3		V2S4				
	6	V1S3	V3S3		V3S2		V1S2		V1S1		V3S1		V3S4		V1S4		V1S3		V2S3		V2S2		V2S1		V2S4		V2S3				
	7	V1S2	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	V3S1		V3S4		V1S4		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	V3S3		V3S2		V1S2		V1S1	V1S3			V2S4		V2S3		V2S2		V2S1					
	13	V3S4	V1S4		V1S1		V3S1		V3S2	V1S2 \	V1S3		V3S3		V3S4	V3S2	V1S2			V2S1		V2S2		V2S3		V2S4					
	14	V3S3	V1S3		V1S2		V3S2		V3S1	V1S1 D15	V1S4		V3S4		V3S3	V3S1	V1S1			V2S2		V2S1		V2S4		V2S3					
	15	V3S2	V1S2		V1S3		V3S3		V3S4	V1S4	V1S1		V3S1		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	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	V3S1	V3S1			V2S2		V1S1		V2S4		V2S1		V2S2			
	24		V3S1		V1S1		V1S4		V3S4		V3S3		V1S3		V1S2 /	V3S2	V3S2			V2S1		V1S2		V2S3		V2S2		V2S1			

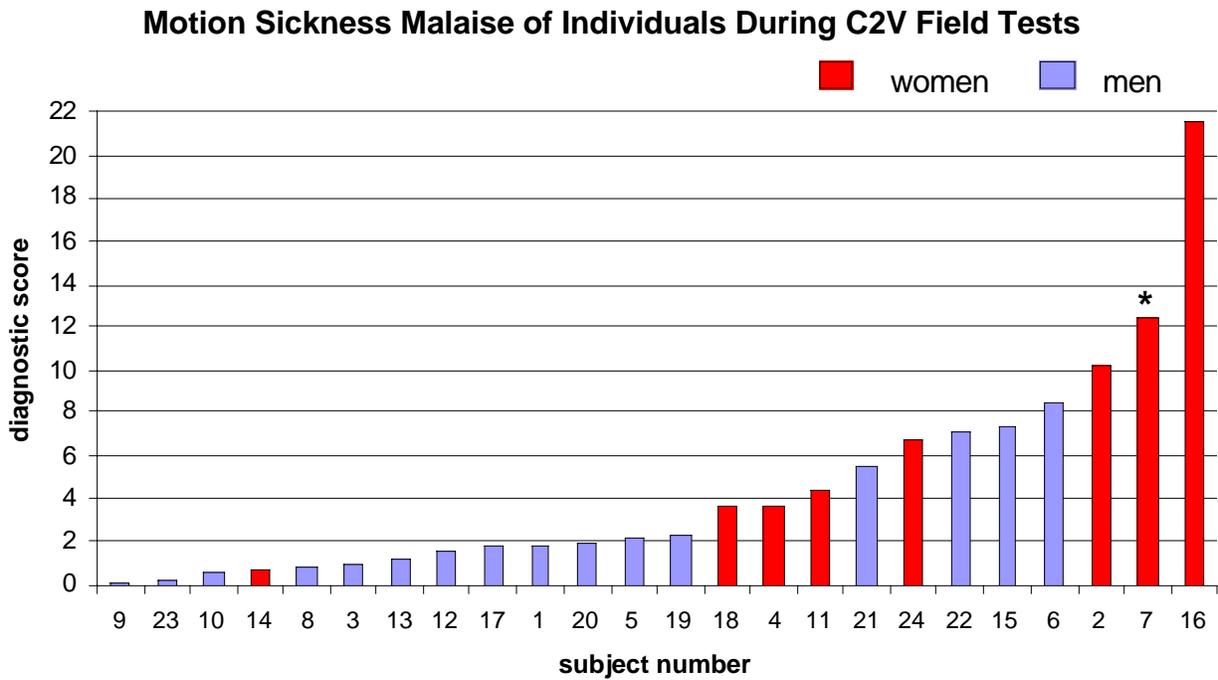


Figure 8. Mean malaise scores of each soldier, averaged across vehicles, seats, and conditions. *Subject 7 withdrew from the experiment.

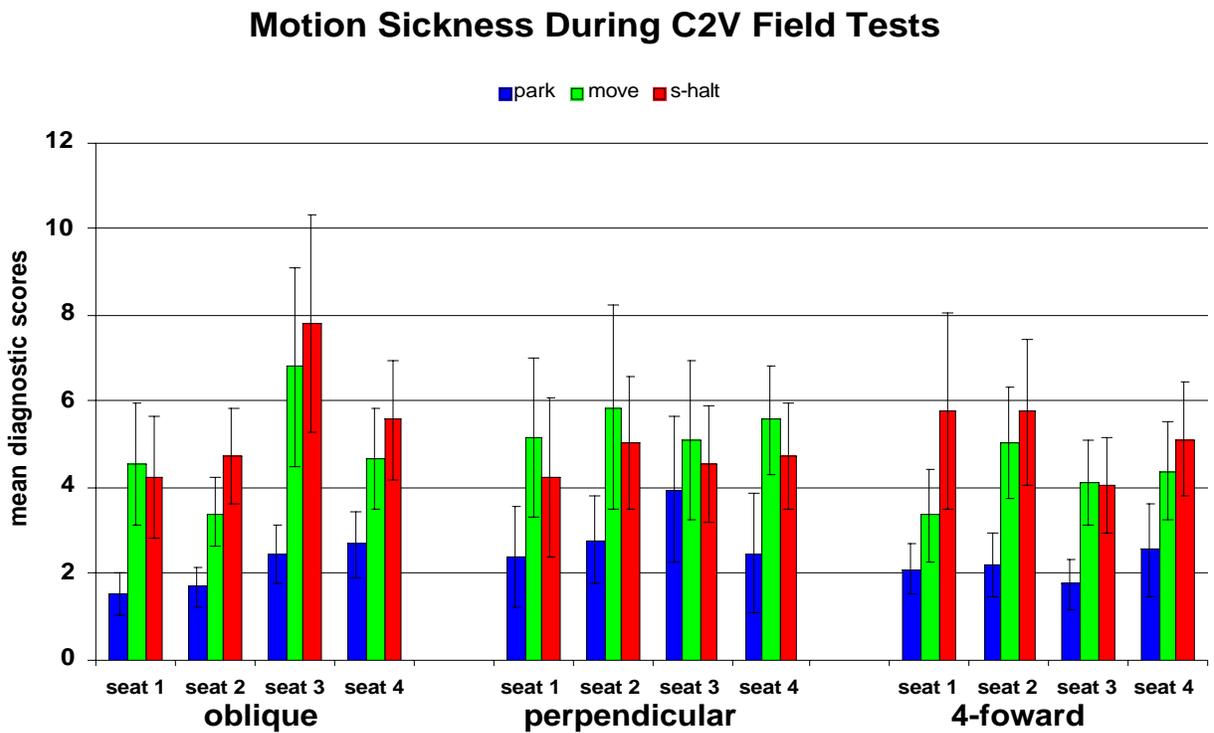


Figure 9. Average malaise scores in each vehicle and seat during park, move, and short-halt conditions (n=23 subjects).

Specific Motion Sickness Symptoms Reported

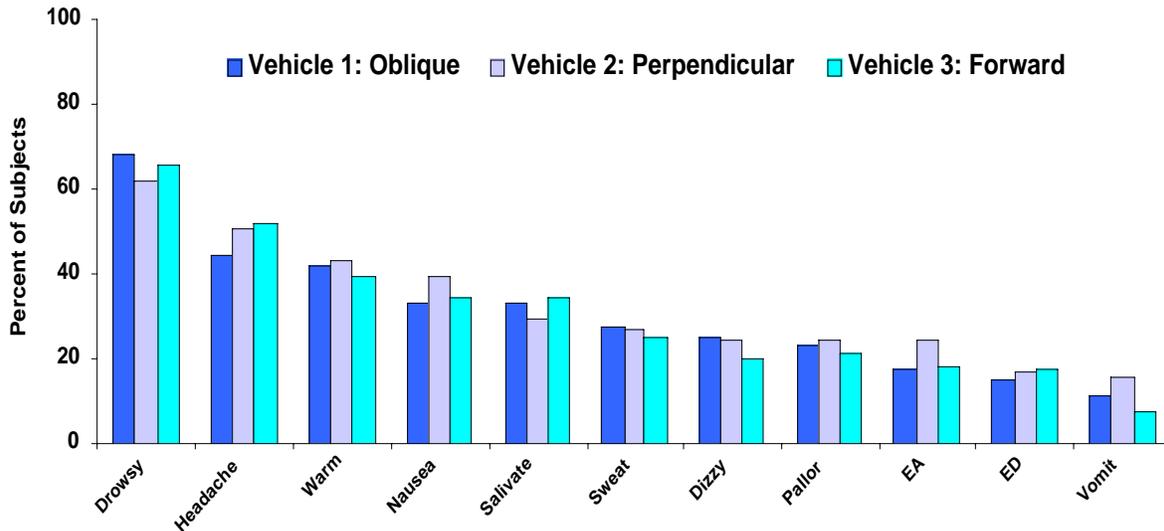


Figure 10. Percentage of subjects reporting specific symptoms during C2V field operations.

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 threefold 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 of sleep obtained on the nights prior to field tests (Spearman-rho, $r=0.18$). 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 $U=62.5$, $p=ns$).

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's sleep loss. Attention lapses in the reaction time or grammatical reasoning subtests in these subjects were noted by the experimenter prior to knowledge of their sleep loss since they are a common symptom of the effects of sleep loss on performance (ref. 9).

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 posttest 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.

Drowsiness Reported During C2V Field Tests

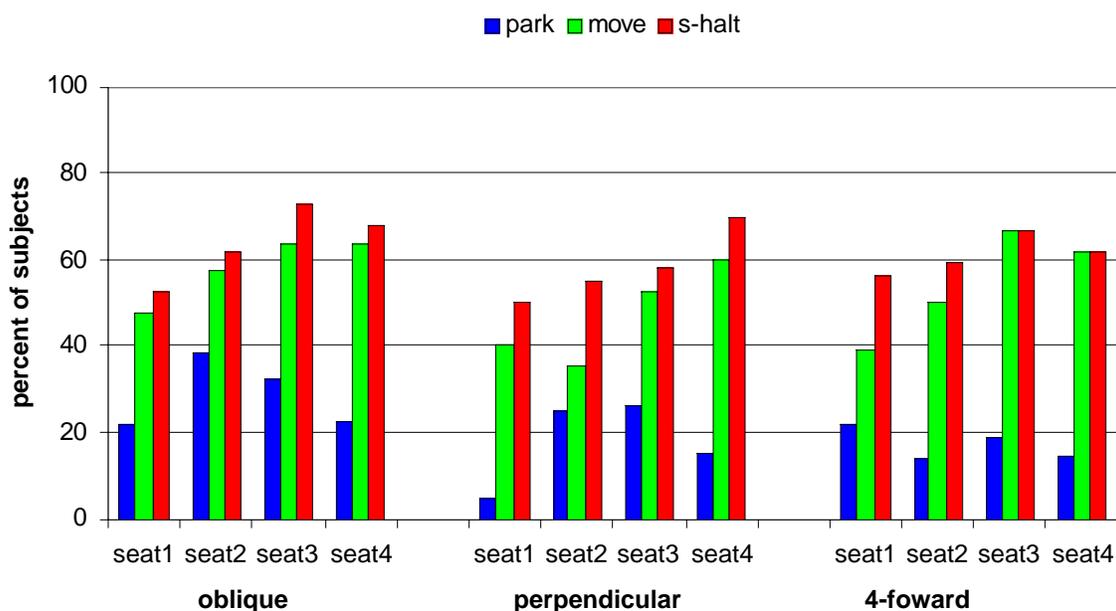


Figure 11. Percentage of subjects reporting drowsiness in each seat and vehicle across conditions in the field tests.

Table 4. ANOVA Results of Performance Subtests

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

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 interactions of vehicle x condition and seat x condition. 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 (ref. 10) 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, which 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, there were still significant

Table 5. Tukey’s HSD Multiple Comparisons: Interaction of Vehicle x Condition

Park vs. Move			
	Oblique	Perpendicular	4-Forward
COMPOSITE	p<4.05E-06	p<2.26E-06	ns
NPTAP	p<2.32E-06	p<2.26E-06	ns
MANIKIN	ns	p<0.002	ns
REASON	ns	p<0.00008	ns
Park vs. Short-halt			
COMPOSITE	p<0.004	p<0.03	ns
NPTAP	p<0.0001	ns	ns
MANIKIN	ns	ns	ns
REASON	ns	ns	ns
Move vs. Short-halt			
COMPOSITE	ns	p<0.002	ns
NPTAP	ns	p<0.02	ns
MANIKIN	ns	ns	ns
REASON	ns	P<0.003	ns

performance decrements in all subtests observed 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. And 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.

In vehicle 3 (4-forward) there were no significant changes across any of the conditions for COMPOSITE and 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. 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 significant only for PHTAP. Post-hoc tests showed PHTAP was significantly degraded in all seats ($p < 0.02$ or lower) except for seat 4, the one located in the front of the vehicle and which 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 (most rear) in the oblique vehicle was this task significantly degraded, and only during the short-halt condition ($p < 0.01$ or lower).

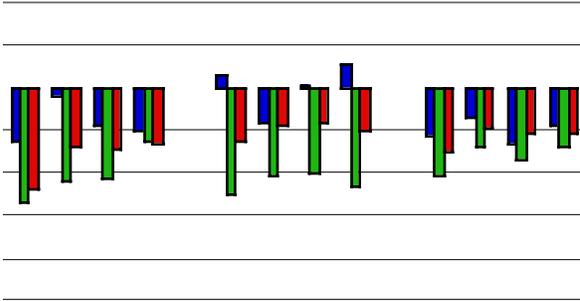
A method for describing the degree of performance decrement observed in this experiment was based on a percent change from baseline scores (fig. 12). Baseline scores for each subtest for each subject were computed as the average of the last training session (trial 8) performed in the classroom prior to 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 for practice effects, which modulated performance levels during the field test batteries. These practice effects occurred during the course of 31–86 repetitions of the performance test batteries performed by the soldiers. Due to the differing 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 (ref. 11). The probability of at least five subtests exceeding this criterion is $p < 0.02$, based upon a Monte Carlo simulation of performance subtest changes using performance data obtained from a prior human study (ref. 6). This impairment occurred in nearly half (11 of 24) of the participating soldiers. 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 (fig. 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% (ref. 12), 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 (ref. 13), and $BAL\% > 0.025$, which is the minimum level found to be associated with significant operational performance errors (ref. 14).

Performance Changes From Baseline During C2V Field Tests



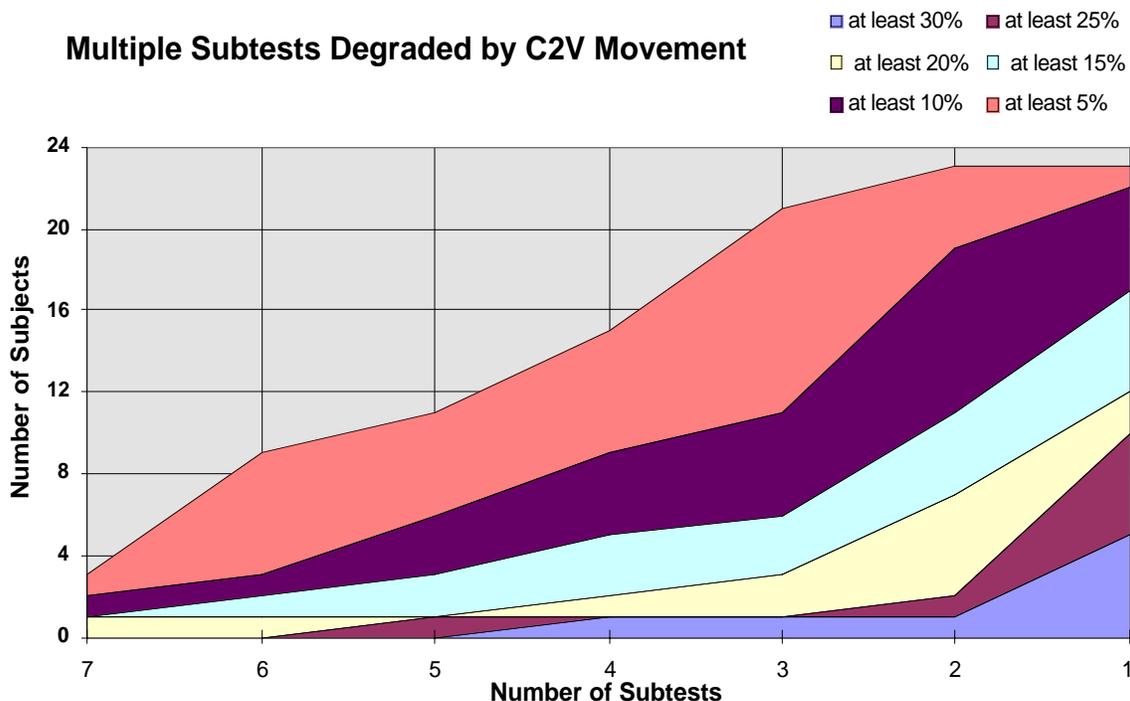


Figure 13. Number of subjects showing degraded skills of 5% to 30% on one to seven of the performance subtests.

Figure 14 shows performance-based blood alcohol level equivalency scores (BAL%) of subjects during park, move, and short-halt (all days). In the park condition 3 subjects showed BAL% >0.08, and four subjects exceeded the performance criteria (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%.

Mood and Sleep

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 (i.e.,

self-perception of readiness) reflects feelings or emotion associated with a mental state. This score is 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, $p < 1.63E-08$, and chi square=88.23, $p < 1.73E-06$, respectively). It is clear from 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 ($p < 0.01$) from park to move and 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. 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 ($p < 0.05$) 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, $p < 0.000001$). Post-hoc Wilcoxon paired tests showed that the activation mood dimension declined from pre-field test training to park, $p < 0.03$. The affective mood dimension also declined from training to park, $p < 0.005$.

In the present study, there were three measures of sleep: (1) 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, (2) “trouble falling asleep” and (3) “number of waking episodes on the previous night.” Figure 17 shows the average amount of sleep obtained by soldiers on the nights prior to C2V field tests.

The mean sleep duration reported during the field exercises was 6.3 hours per night, where individuals’ self-reported

sleep durations ranged from 1.5 to 16 hours. An ANOVA on 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 ($F = 2.93$, $df = 6, 132$, $p < 0.03$); however, post-hoc comparisons did not reveal any significant differences within or between vehicles for each seat.

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 prior to 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 6). 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 5 of 7 subtests known to affect operational efficiency (ref. 11).

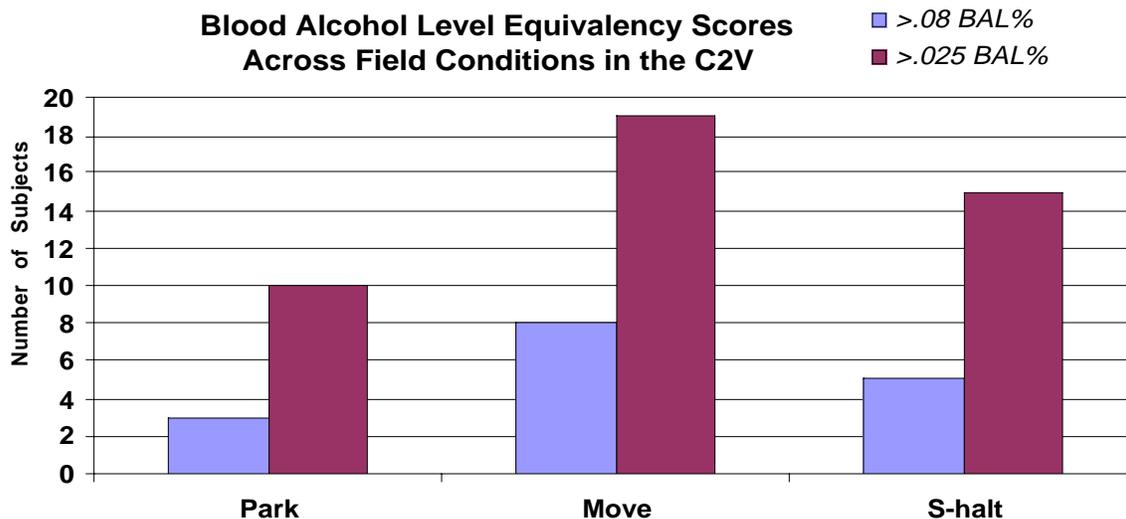


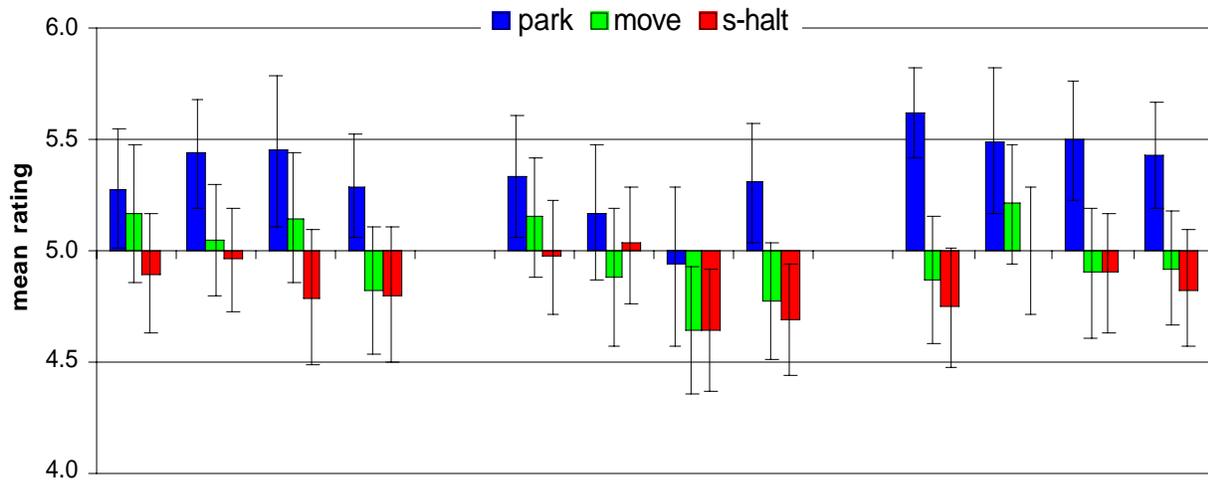
Figure 14. Number of subjects with performance based BAL% scores of >0.08 and >0.025 .

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 due to anomalies in his data.

Activation Mood Dimension



Affective Mood Dimension

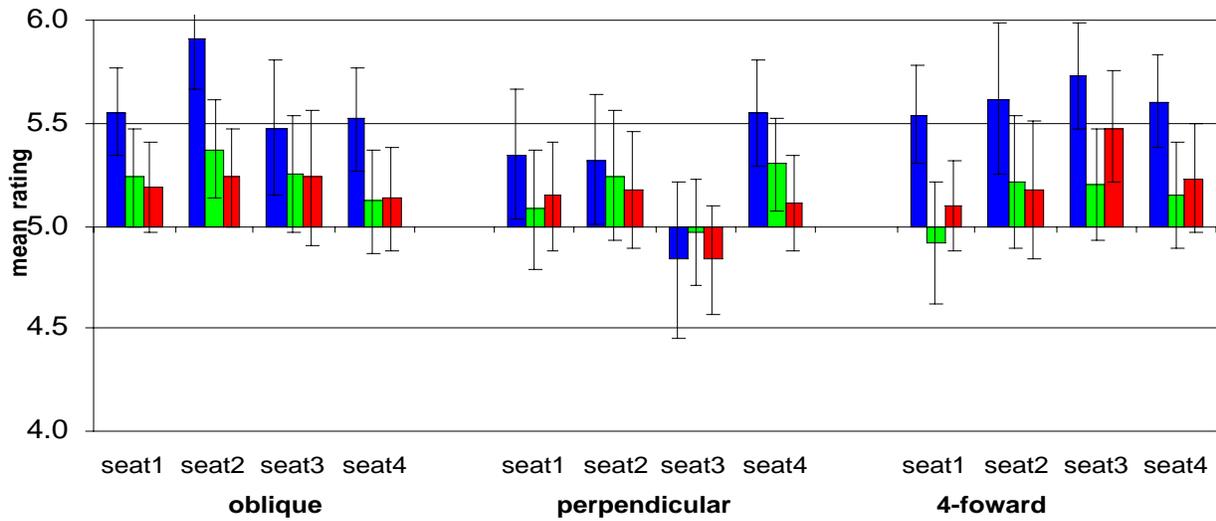


Figure 15. Activation and affective mood dimensions across field conditions (n=23 subjects).

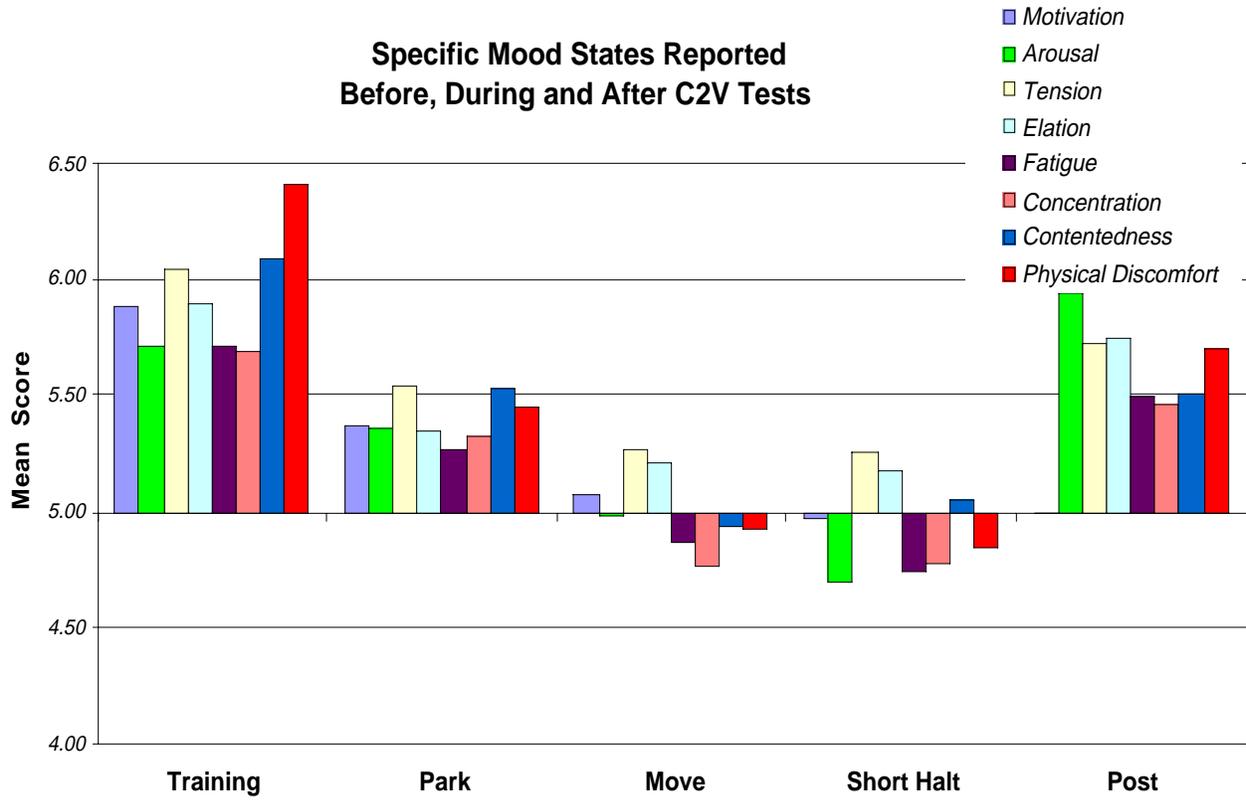


Figure 16. Mood scores of the last day of training compared to three field conditions and a classroom test at the end of the experiment.

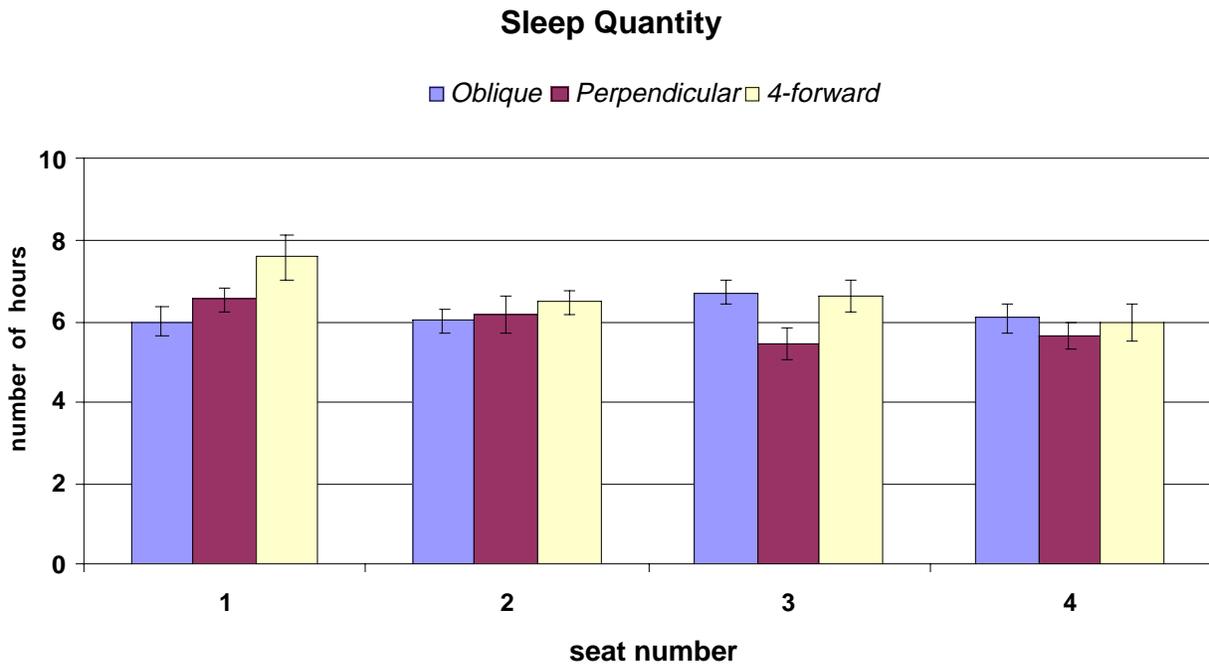


Figure 17. Sleep duration reported on the night before C2V field tests (n=23 subjects).

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 reduced to 15-second averages for each physiological channel. 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 on 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 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 interactions of vehicle x condition and seat x condition.

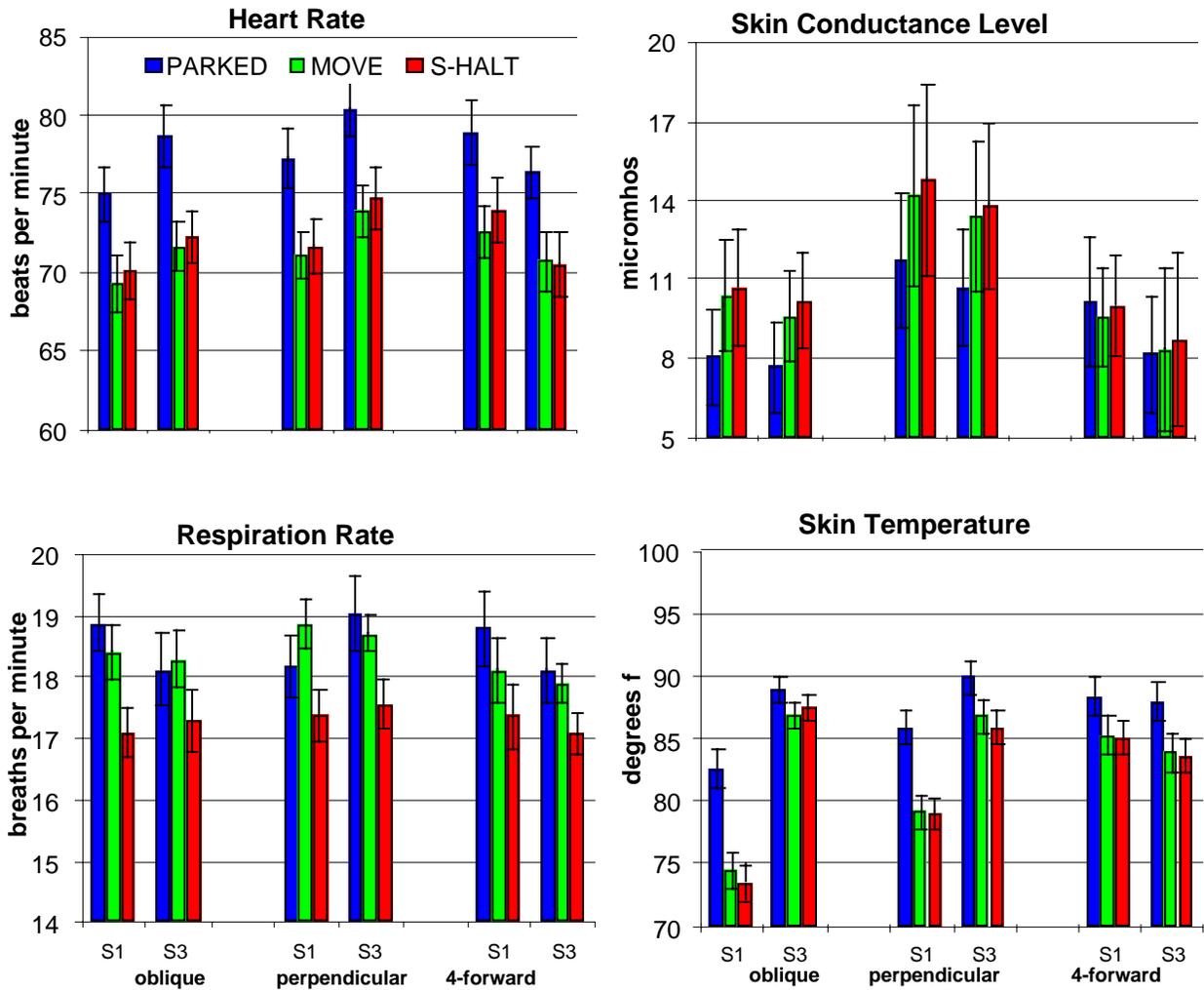


Figure 18. Means (± sem) of physiological responses during C2V field tests (N=23 subjects).

Table 7. Summary ANOVA Results of Physiological Response Means

Source	df	Heart Rate		Respiration		Skin Conductance		Temperature	
		F	p<	F	p<	F	p<	F	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 main effect for condition was significant for all four physiological response means. Post-hoc comparisons (Tukey’s HSD) of the park vs. move conditions were significant for heart rate ($p < 0.006$) and skin temperature ($p < 0.003$). Comparisons for park vs. short-halt were significant for heart rate ($p < 0.01$), respiration rate ($p < 0.001$), and skin temperature ($p < 0.001$). The comparison for move vs. short-halt was significant only for respiration rate ($p < 0.004$). 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.

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 ($p < 0.0003$) and short-halt ($p < 0.005$).

The accelerometer transducer, 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. ANOVA was performed on the x-axis data only, as the other two axes (y and z) were compar-

ble. Only the main effect for conditions was significant ($F = 148.29$, $df = 2,44$, $p < 9.99E-16$). Post-hoc comparisons of conditions were all significant ($p < 0.00001$).

A second metric used to characterize physiological changes to 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 on 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 vs. move conditions were significant for respiration rate ($p < 0.0003$) and skin temperature ($p < 0.0001$). Comparisons for park vs. short-halt were significant for heart rate ($p < 0.00001$) and respiration rate ($p < 0.01$). The comparison for move vs. short-halt was significant for heart rate ($p < 0.0005$) and skin temperature ($p < 0.001$). 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

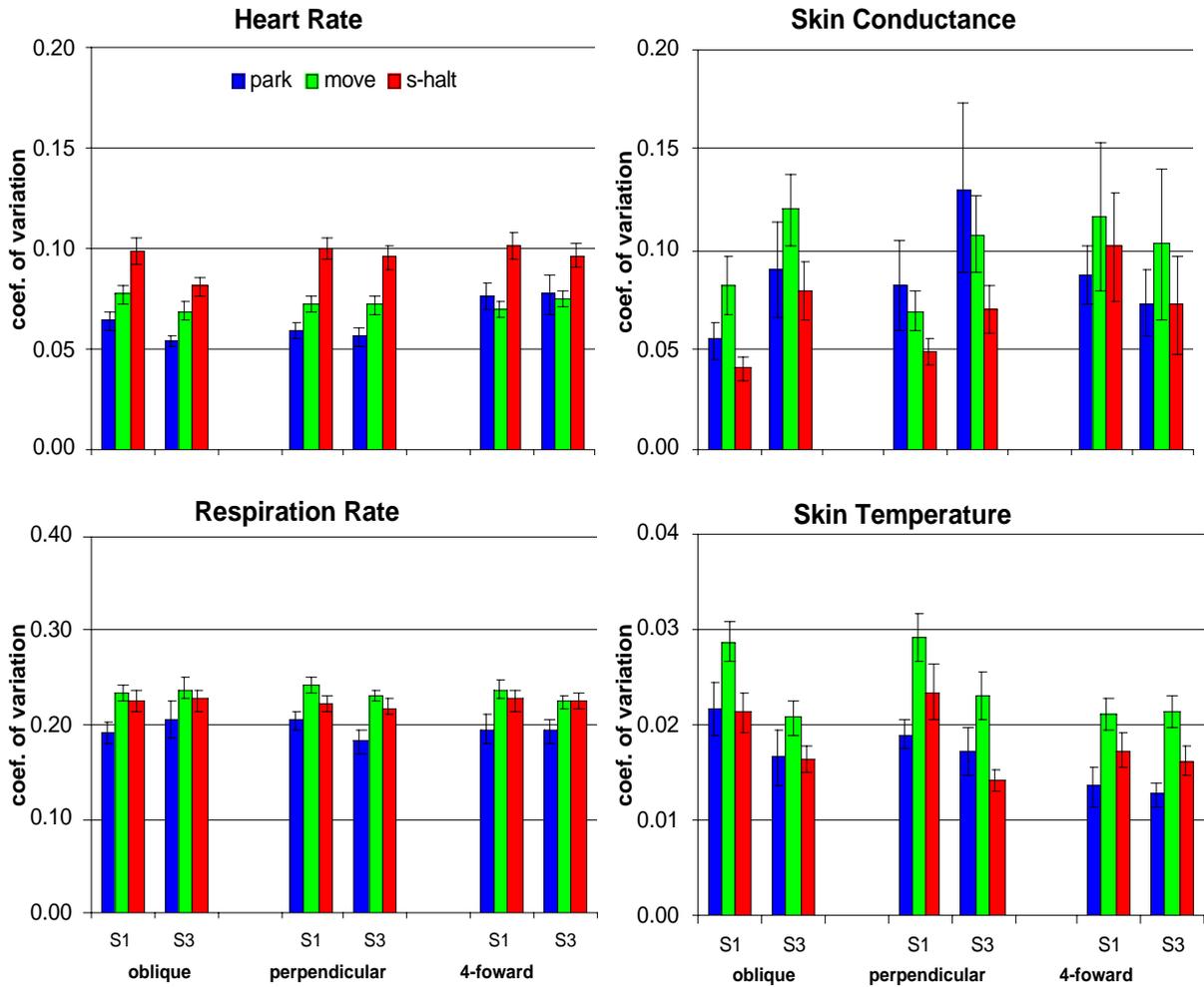


Figure 19. Physiological response variability, expressed as means of the coefficient of variation (\pm sem) across vehicles, seats, and conditions ($n=23$ subjects).

Table 8. Summary ANOVA Results of Physiological Response Coefficient of Variation

Source	df	Heart Rate		Respiration		Skin Conductance		Temperature	
		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; where some subjects show larger magnitude responses in one variable than another (refs. 8 and 15–19). Continuous physiological monitoring during the 4-hour field tests provided more information about environmental impact on 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. 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. Figure 20 shows that subjects with low performance had higher heart rate levels and greater variability on all parameters than subjects with high performance scores. Also it is 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 physical reaction to these environmental changes.

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 (ref. 20). 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 there was some drowsiness 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 (ref. 21). Working in moving environments may induce Motion Induced Fatigue, which results in twice the fatigue level as working in a stable environment (ref. 22).

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 US Navy research group (ref. 7) and has been used extensively by researchers in this field (refs. 8, 18, 23, and 24). It consists of easy to understand questions regarding specific symptoms experienced, which are later subjected to a standardized scoring method allowing comparisons across many studies and environmental conditions. It is, nonetheless, a subjective scale, which depends heavily

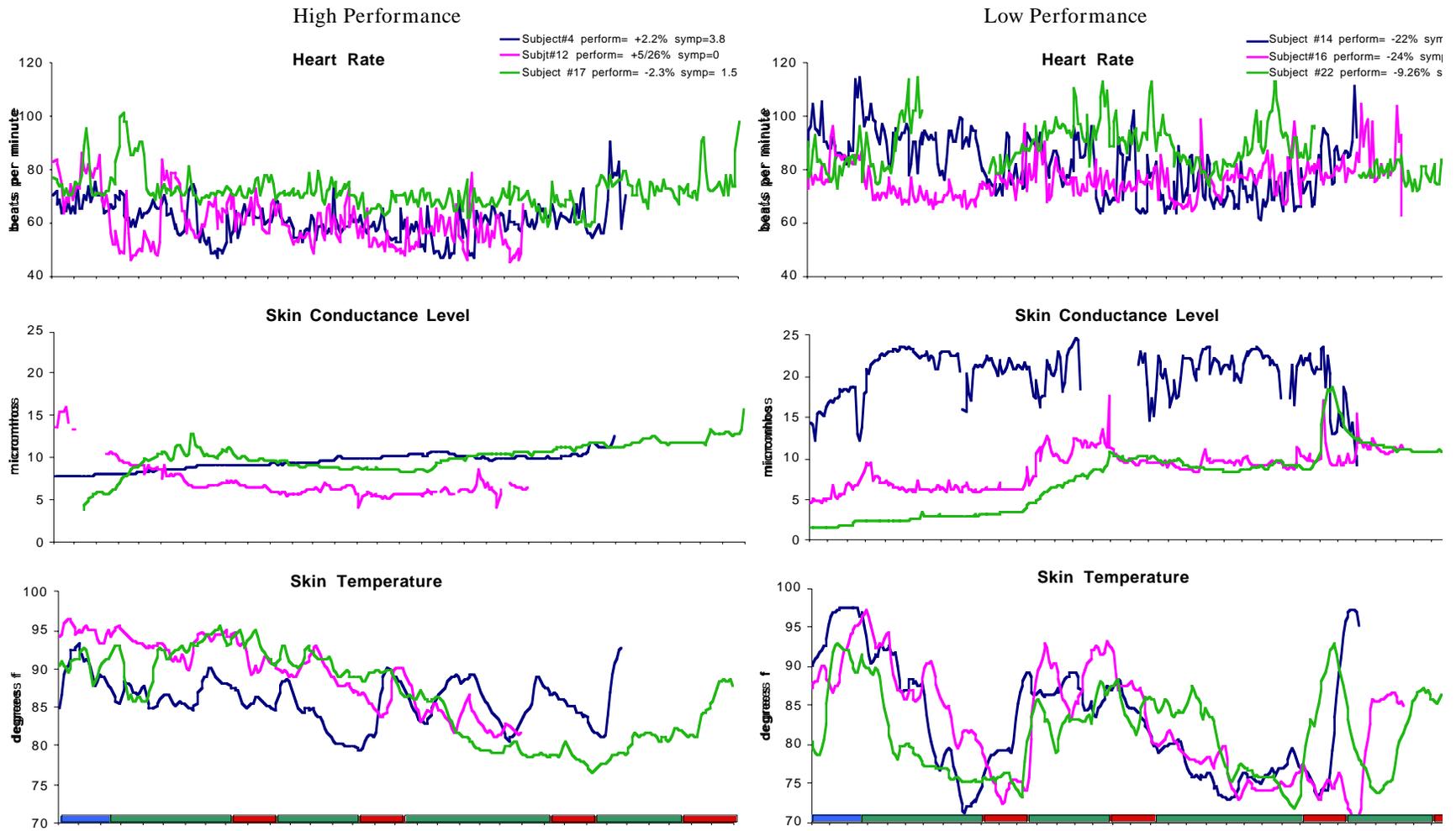


Figure 20. Physiological responses to C2V conditions. Color bar on x-axis: park (blue), move (green), and short-halt (red).

on the accuracy of individual reports. In most research environments, the subject's report is complemented by simultaneous observations by a trained investigator. Such symptoms as "pallor" for example, require that another person observe the subject to provide a rating. In the present study, there were no observers trained on 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 was similar to 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 pretest classroom instruction period.

Despite the lack of trained observers and inconsistent reports on 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 on the etiology of motion sickness as a function of sensory conflict (ref. 25), where 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 slowing down of work rate and disruption of continuous work (ref. 22).

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 on the C2V (ref. 3) 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 and/or a deterioration in motivation and concentration due to 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 (refs. 26 and 27). The Delta performance battery employed in the present study has been shown in several studies to reliably predict military operational performance (refs. 11, 28 and 29).

The number of performance batteries completed during the C2V field tests ranged from 31 to 86 trials, which resulted in differing amounts of practice for test participants. The reliability of the percent calculated decrements is dependent 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 detrending of the individual practice effects for each subtest. Despite the lack of detrending of these data thus far, it is noted that all subjects were found to have reached a performance plateau after only 1-6 trials during training in the classroom.

Performance decrements associated with different BAL% levels were established by Kennedy (ref. 12) and were employed in our own research on performance effects of promethazine (ref. 5). However, the BAL% conversion formulas used in the 1996 study were based on a double blind design with placebo controls, which was not available in the present study. Further earlier tests were based on the DELTA precursor test battery (Automated Portable Tests System), 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 (ref. 30), in which significantly higher levels of performance were found for most subtests using the PC-based DELTA subtest versions. However, intra- and intertest 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 (ref. 30). Therefore, it was valid to convert performance decrements to BAL% scores in this study, which utilized the DELTA battery based upon conversion formulas developed from a previous study utilizing 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 there was a substantial negative impact on cognitive and psychomotor performance 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 subjects' perception of the environmental impact on his/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 posttests 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, both on quantity and quality of sleep obtained on nights prior to 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 (refs. 31–34). There was considerable variability in the amount of sleep obtained, despite instructions to subjects to avoid late night 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 20–29 year olds (ref. 35).

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 microsleeps (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 due 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 (ref. 36).

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 15–20-minute naps have been shown to improve subjective sleepiness, task performance and self-rating of task performance (refs. 37 and 38). Naps of 0.5–2 hours duration resulted in significant improvements in reaction time, physiological activation indices and subjective states (refs. 39 and 40). Mood variables such as self-reported sleepiness, fatigue, and activation consistently improve after naps (ref. 41).

However, several studies have not observed improved performance after naps relative to prenap performance levels (ref. 41). 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 postnap performance (sleep inertia), and the type of performance task (ref. 42). Sleep inertia, the time period immediately following awakening from sleep can, in fact, result in performance task impairment and/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 (ref. 42). This phenomenon lasts for at least 5 minutes in nonsleep-deprived subjects (ref. 41) and is essentially dissipated within 35 minutes (ref. 43) but has been observed for as long as 2 hours post-nap (ref. 39).

Jewett (ref. 44) also found that performance could be impaired for more than 2 hours after awakening in a comprehensive study on 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. Specific performance tests shown to be negatively impacted following rapid awakening included reaction time, visual-perceptual tasks, and various cognitive tasks (ref. 45). The documented observations of 37 incidents of 16 soldiers napping during the C2V field tests suggests 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 which 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 on 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 (ref. 8). Further, autonomic response patterns to motion stimuli were highly idiosyncratic; however, the same subjects tended to produce stable response profiles to repeated motion sickness tests (refs. 18 and 19). The 1990 study identified 12 different response patterns among 58 test participants, with subjects showing stability in one to four of these responses. Some of the subjects showed large increases (sympathetic-like) 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 (ref. 16). However increases in skin conductance level and concomitant decreases in skin temperature (i.e., peripheral vasoconstriction) reflect sympathetic activation associated with emotional distress (ref. 46). These data, therefore, are indicative of autonomic imbalance, suggesting inadequate homeostatic controls (ref. 17).

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 both increase motion sickness tolerance and improve pilot performance under emergency flying conditions (refs. 23, and 47–57).

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 10–25 Hz (ref. 58). Lower frequencies (between 0.12 and 0.4 Hz) have been found to be associated with inducing motion sickness symptoms (refs. 18, and 59–60). Effects of vibration on manual dexterity as measured by tracking tasks showed greatest number of errors occurred at 5–11 Hz (ref. 61). The accelerometer data from the AFS-2

showed significant increases in mean amplitude during move conditions relative to park or short-halt, but there were no significant differences found between vehicles or seats. Vibration data obtained from accelerometers mounted at the front and rear seats of the vehicles showed the energy in the power spectral density plots was concentrated around 5 Hz in the vertical direction (ref. 62). 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 twelve C2V field tests by the end of the study (approximately 40–50 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 (ref. 63). 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, more than 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 that 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 US Army inventory exceeded the noise-limits for verbal communication and required hearing protection to prevent damage (ref. 64). Studies have shown that noise can induce lapses in vigilance or sustained attention (ref. 65), complex mental, psychomotor, and perceptual tasks (ref. 66) and impairs reaction times (ref. 67).

The data collectors on each vehicle recorded ambient air temperatures and relative humidity daily. Review of these data showed that despite periods where the doors were

opened due to 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 degrees Fahrenheit) measured in skin temperature of some of the test participants when field conditions changed. And, although there were some documented complaints of odors due to air-conditioner failures, measures of toxic fumes in the C2V were reported to be well below hazardous levels (ref. 68).

Conclusions

Although other analyses could be performed on these data (e.g., correlations between individual physiological responses and specific motion sickness symptoms, detrending 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 an individual crewmember's functional state during spaceflight. Studies in space of this methodology have been severely limited by the infrequency of flight opportunities and 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 under operational conditions, and has therefore accomplished an important goal for the space agency as well as 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 where 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 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 were 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 posttests conducted in a classroom facility.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE July 1999	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Effects of Command and Control Vehicle (C2V) Operational Environment on Soldier Health and Performance		5. FUNDING NUMBERS 199-14-12-50	
6. AUTHOR(S) Patricia S. Cowings, William B. Toscano,* Charles DeRoshia, and Richard Tauson†			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Ames Research Center Moffett Field, CA 94035-1000		8. PERFORMING ORGANIZATION REPORT NUMBER A-99V0027	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA/TM-1999-208786	
11. SUPPLEMENTARY NOTES Point of Contact: Patricia S. Cowings, Ames Research Center, MS 239-16, Moffett Field, CA 94035-1000 (650) 604-5724 *University of California, Los Angeles, CA †Army Research Laboratory, Aberdeen Proving Grounds, MD			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified — Unlimited Subject Category 53 Availability: NASA CASI (301) 621-0390		12b. DISTRIBUTION CODE Distribution: Standard	
13. ABSTRACT (Maximum 200 words) The purpose of this project was to use NASA technology to assist the US Army in the assessment of motion sickness and performance of soldiers in the Command and Control Vehicle (C2V). Three different vehicle configurations were tested: oblique, (3 seats at a 20-degree angle from the direction of travel); perpendicular, (3 seats at a 90 degree angle); and 4-forward, (all seats faced forward). In all vehicles, the front seat faced forward. Sixteen men and eight women participated for 15 days: 2 days of classroom instruction; 12 days of field tests in the C2V, and 15 minutes of post-field test performance measures. Conditions for field tests were: an initial Park; four Moves (i.e., travel over a mixed terrain); and four Short-halts following movement. NASA task batteries, mood and symptom scales, and physiological data were collected during field tests. Motion sickness symptoms ranging from slight to severe were reported for all subjects. Conclusions were: (1) there was no difference between vehicle configurations; (2) there was a negative impact on crew performance and health when subjects attended to visual screens during vehicle movement; and (3) symptoms and performance degradation were not mitigated by intermittent short-halts.			
14. SUBJECT TERMS Motion sickness, Human performance, Armored vehicles, Autonomic nervous system		15. NUMBER OF PAGES 40	
		16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT