ARMY RESEARCH LABORATORY

Quantification of Cognitive Process Degradation While Mobile, Attributable to the Environmental Stressors Endurance, Vibration, and Noise

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Abstract

Operator cognitive performance was quantified in an off-road environment by repeatedly administering a battery of cognitive measures to assess the genus and degree of performance while mobile. Environmental stressors referred to as *endurance*, tracked vehicle *vibration* per intensity, and *noise* were recorded over the course of one day per participant (n=18). Vibration conditions presented were varying amplitudes approximating accelerations of 0.88 *g* by a frequency of 3 cycles per second (cps), 0.65 *g* by 4 cps, and 0.03 *g* by 12.5 cps. Observed collectively, the predictor variables returned a multiple R value for the dependent variable percent correct of 0.733 ($p < .0001$) and for the dependent time to complete of 0.649 ($p < .0001$). Although all stressors significantly influenced performance, uncovered was a repeated order of effect per method of evaluation, beginning with the measure *endurance*, then *session*, followed by *absorbed power* recordings, then *exposure limit* criteria comparison, and finally, *noise*. Cognitive performance decrement measured as percent correct was found for the cognitive concepts *time sharing, selective attention, inductive reasoning, spatial orientation, speed of closure,* and *memorization.* Measured as percent of time taken to complete tests, degradation was found for the concepts *speed of closure, time sharing, inductive reasoning, spatial orientation, selective attention,* and *memorization.* This investigation displayed the existence of dose response relationships, higher doses of vibration associated with more unfavorable effects. Additionally, the trials effect recorded indicates that performance deteriorated as a function of time in the environment.

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EXECUTIVE SUMMARY

This exercise was performed to contribute to research initiated for enhancing command and control (C^2) operations in future environments, which will be more mobile than in the past. The objective was to quantify operator cognitive performance in an off-road environment by repeatedly administering a battery of cognitive measures to assess the genus and degree of performance degradation while moving. As experimental conditions transpired, environmental stressors referred to as *endurance* while mobile (measured as minutes in the environment, and by between test session performance during vibration exposure conditions at three levels of intensity), tracked vehicle *vibration* (collecting absorbed power measures and by comparison with exposure limit criteria), and *noise* (in dBa) were recorded over the course of one day per test participant (n=18) and later observed to determine their influences on performance. Vibratory conditions presented were varying amplitudes approximating accelerations of 0.88 *g* by a frequency of three cycles per second (cps) while traveling 20 miles per hour, 0.65 *g* by 4 cps at 10 mph, and 0.03 *g* by 12.5 cps at 0 mph.

Cognitive concepts selected for observation were *selective attention*, *inductive reasoning*, *time sharing*, *memorization*, *spatial orientation*, and *speed of closure*. Psychometrics chosen to evaluate these were, respectively, the "Continuous Recall" task, the "Mathematical Processing" task, the "Grammatical Reasoning" task, and "Sternberg's Memory Search" (from the Criterion Task Set), and the "Route Planning" and "Missing Items" tests (from the Complex Cognitive Assessment Battery). Perceived stress was also assessed using an ARL Modified Stress Battery, which includes an amylase enzyme assay.

Observed collectively, the predictor variables returned a multiple R value for the dependent variable percent correct of .733 ($p < .0001$), and for the dependent time to complete of .649 ($p < .0001$). Although all stressors significantly influenced performance, uncovered was a repeated order of effect per method of evaluation beginning with the measure *endurance* exhibiting most influential affect, then *session*, this followed by *absorbed power* recordings, next *exposure limit* criteria comparison, and finally *noise*.

Results revealed the tests selected as capable of measuring their associated concept. Cognitive performance decrement, measured as percent correct of test scores, was found greatest for the concept *time sharing* (a 46% decrease from baseline, over the course of one day). The next greatest influences were found for *selective attention* (a 37% decrease) and *inductive*

reasoning (also a 37% decrease); these were followed closely by *spatial orientation* (a 36% decrease), then *speed of closure* (a 34% decrease), and finally *memorization* (a 21% decrease from baseline) found least to degrade in the environment. Measured as percent of time taken to complete tests, environmental effect was found greatest for the concept *speed of closure* (an increase of 40% in time taken to complete test, over the course of one day). The next greatest influence was on *time sharing* (a 27% increase), which was followed by *inductive reasoning* (a 24% increase) and closely by *spatial orientation* (a 23% increase), then *selective attention* (a 21% increase). Once again, memorization (a 7% increase in time from baseline) was found least to degrade in the environment.

This investigation also displayed the existence of dose response relationships, higher doses of vibration associated with more unfavorable effects. Additionally, the trials effect recorded indicates that performance deteriorated as a function of time in the environment and did so consistently by the fourth hour of operation. The trend of the data suggests that had testing continued for a longer period of time, the trials effect would have been greater.

QUANTIFICATION OF COGNITIVE PROCESS DEGRADATION WHILE MOBILE, ATTRIBUTABLE TO THE ENVIRONMENTAL STRESSORS ENDURANCE, VIBRATION, AND NOISE

INTRODUCTION

Background

The purpose of conducting this field exercise was to support research being performed to enhance command and control (C^2) operations in future environments, which will be more mobile and less staffed than past situations. Preference for such operations was realized during the recent Gulf War, where commanders functioning in a higher technological environment than before became aware that the conduct of a tactical operations center (TOC) would have been more advantageous if less vulnerable and better able to keep pace with fast moving forward forces. Evidence for the significance of this requirement is the fabrication and acceptance by the purchase of FMC (not an acronym), Inc.'s, command and control vehicle (C^2V). The Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) is currently providing human factors support to the C^2V program.

Research Approach

To replicate a TOC, especially one modifiable for research purposes, is quite difficult, given the high level of activity that normally takes place. Concurrently, it must be assumed that such action occurring in a prototype C^2V, considering reduced crew and mobility requirements, will place even more demand on operators, which only amplifies the essentiality for assessing the genus and degree of human performance degradation. An approach of observing cognitive function degradation was adapted, selecting processes from what is known to take place in a C^2 environment. For this, the work of Dr. Edwin A. Fleishman was referenced as a reasonable and thorough approach for quantification procedures guidance, as well as valuable background reference. Fleishman's taxonomy (Fleishman & Quaintana, 1994; Fleishman & Hogan, 1978), which was adapted by researchers at ARL, focuses on high-order cognitive capabilities such as planning, problem solving, and decision making. The approach begins with a schematic of the constructs to be measured and proceeds to the selection of tests for measuring these higher order constructs assessed by lower order tests. For an assessment battery of this nature to be effective, one must consider the constructs involved in this situation, namely, complex cognitive tasks. These tasks may be divided by two tiers: (a) high-level cognitive capabilities, defined as post-sensory motor processes involving conceptually driven operations, followed by (b) conceptually driven operations, those in which post knowledge is applied to current data or thoughts (Norman, 1983). In all, Fleishman names 51 concepts, referring to them as *cognitive skills and experiences*. At present, ARL researchers are attempting to quantify these for future input to a model of human performance. What remains necessary is the selection of adequate, field-validated, cognitive tests and the appropriate methods for investigation to elicit data for this model. The current effort is one attempt at this.

To make this endeavor reasonable, it was necessary to select representative cognitive skills, logically electing to observe those most important in a TOC environment. For this, reviews of individual task analyses were performed and subject matter experts (SMEs) consulted. Associating the results of reviews with Fleishman's *cognitive skills and experiences* allowed the number of skills observed to be reduced, permitting a judicious field exercise. The subset of skills selected, with given definitions, appear as Appendix A. Following a logical progression, the literature about cognitive testing was surveyed to find tests that would evoke valid results in a robust environment (stimuli received from various sources). Here, considerations had to be made to ensure that the tests selected were readily available, possessed validation evidence with histories of successful and reliable usage, and demonstrated the capability of being administered within short periods of time. A brief description of each test selected for this exercise is presented later in the section entitled "the Cognitive Test Battery." With this, it appeared evident that operator emotional and physical stress also be assessed, which was attempted by using tests formulated at ARL (see section entitled "the Stress Assessment Battery").

Lack of an available C^2V and true C^2 operation necessitated that elements from as many cognitive skills as possible, which were required for command and control, be extracted and that logical assumptions of future operator requirements be made while limiting variables were considered. Given the prevailing situation, it was necessary to consider what exercise might be conducted using an M113 (a current issue U.S. Army armored personnel carrier (APC), i.e., the vehicle available), which allows room for only two operator positions. In doing so, it was soon realized that with such a sparse interior, little operator interaction could be attempted. Because C^2 units perform as a team, less attention has been given in the research literature to the role of individual performance. However, both individual and group variables affect group effectiveness. Studies performed show that individual member ability, operationalized either as general intelligence or as specific proficiencies, has an extremely strong influence on group outcome (Heslin, 1964; McGrath & Altman, 1966). There is also research showing relationships associating team member personality traits (such as adjustment, sociability, dependability) with team effectiveness (Heslin, 1964). With this knowledge, it was decided that observing individual performance would be beneficial.

Once all situations were assessed, a decision was made to evaluate only a limited variety of cognitive skills in an environment that simulated a mobile command and control type environment as closely as possible, by testing cognitive skills of hypothetical operators while moving and stationary on off-road terrain. Overcoming the obstacles did, however, afford an investigation that could realistically represent off-road operating conditions while using a vehicle in inventory.

Objective

The primary objective of this effort was to quantify operator cognitive performance while in a military command and control off-road environment, by repeatedly administering a battery of cognitive assessment measures. A secondary objective was to evaluate the psychometrics used.

METHOD

The methodology employed was to (a) conduct a field exercise in an environment similar to a mobile command and control situation, requiring approximately four 40-minute periods of movement and four other periods of the same duration while stationary over one day (per each test participant) and (b) repeatedly administer a battery of six cognitive assessment psychometrics (to assess operator cognitive degradation over time and to estimate the effect of the stressors referred to as tracked vehicle vibration, noise, and endurance while mobile). An additional series of six paper-and-pencil stress measures, coupled with one physical measure, was also issued at logical intervals to determine stress levels and as a alternate means of assessing operator state of preparedness.

EXPERIMENTAL DESIGN

A battery of six cognitive tests, four from the collection known as the "Criterion Task Set" (CTS) plus two tests from the "Complex Cognitive Assessment Battery" (CCAB) (see Figure 1), was administered eight times throughout each day of testing (to two test participants per day). The test battery was given four times while subjects were stationary, twice while they were mobile, traveling at more than 10 miles per hour (mph), and again twice while they were mobile, traveling at approximately 20 mph randomly (see Figure 1). With this, the "stress assessment" battery (see Stress Battery section) consisting of six paper-and-pencil tests was administered at nine intervals (once before test initiation, followed by repetitive administrations immediately after each mobile and stationary condition). After each of these times, a salivary amylase sample was taken from participants.

Stimulus

Stimuli for the design were terrain and speed (one terrain traversed at 0 mph, 10 mph average, and 20 mph average), with speeds used to generate a range of vibration levels. The products for these stimuli were *operational factors* (predictor variables): (a) acceleration magnitude (root mean square [rms]), (b) maximum absolute peak acceleration, (c) total absorption power, (d) noise level within the crew station, and (e) duration (time of exposure to the environment), recorded during each cognitive test. *Cognitive test performances* (criterion variables) were (a) time taken to answer (average per test, per allowed time given) for CTS tests numbers 1 through 4, and CCAB tests numbers 5 and 6; and (b) percent correct (average correct answers per test) for CTS tests numbers 1 through 4, and CCAB numbers 5 and 6.

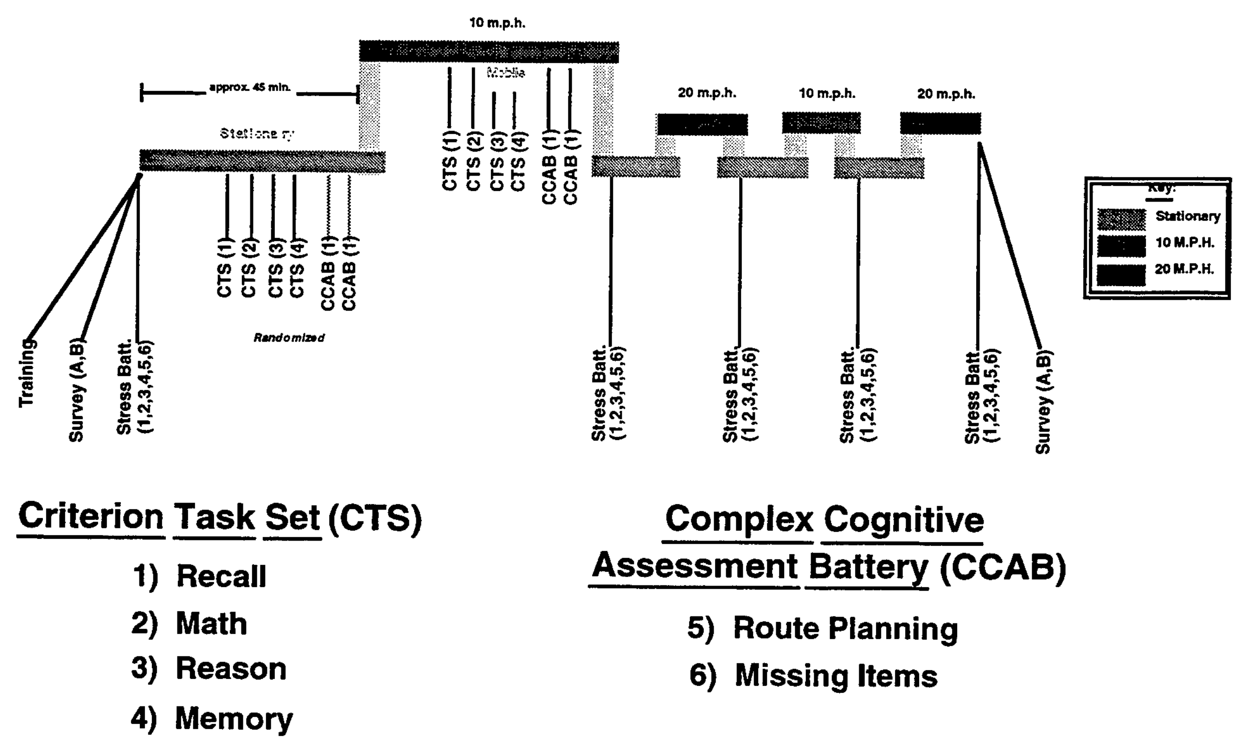


Figure 1. Schema of test administration, given the conditions applied.

Cognitive Concepts

The concepts selected for observation, that is, those believed most consequential (i.e., assigned the largest weight for affect on performance) were (a) *selective attention*, (b) *inductive reasoning*, (c) *time sharing*, (d) *memorization*, (e) *spatial orientation*, and (f) *speed of closure*. The computer-based psychometrics selected to evaluate these concepts follow, respectively, (a) "Continuous Recall Task" (from the Criterion Task Set assessment battery) (b) "Mathematical Processing Task" (CTS), (c) "Grammatical Reasoning Task" (CTS), (d) "Sternberg's Memory Search Task" (CTS), (e) "Route Planning" subtest (from the Complex Cognitive Assessment Battery), and (f) "Missing Items" subtest (CCAB) (see Figure 2).

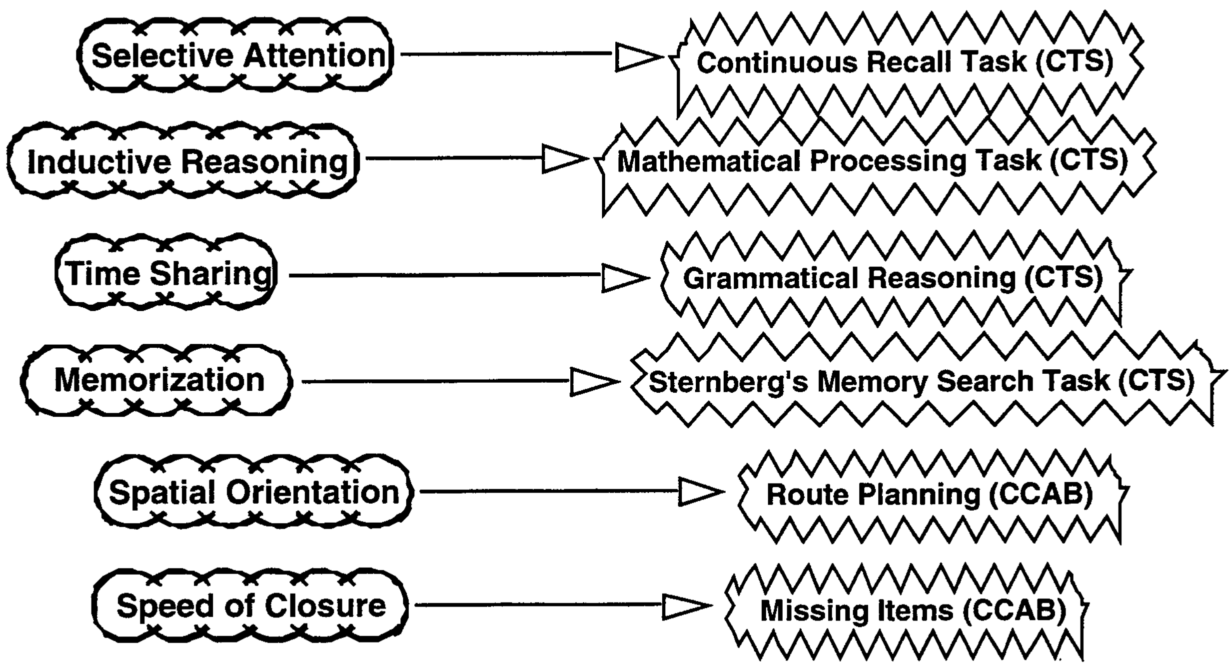


Figure 2. Cognitive concepts associated with appropriate psychometrics.

VIBRATION MEASUREMENT

Vibration is defined as the movement of a mass (the human body) characterized by alternating changes in direction. One classification of vibrations concerns the presence or absence of patterns of movements that reoccur over time. A vibration in which a particular pattern of movement is repeated over equal time intervals is said to be periodic. These are quantified by employing mathematical equations for various waveforms, the simplest of which to qualify is described by the mathematical equation for a sine wave. Vehicular vibrations are *aperiodic* or random in nature, as there is no apparent reoccurring pattern of movement.

Vibration information collected was (a) root mean square acceleration magnitude, averaged *x, y, & z* scale of deviation from a true sinusoidal curve; (b) maximum (positive) absolute peak acceleration (continuous data given in "g," to be used as covariates in the analysis); (c) minimum (negative) absolute peak acceleration (also continuous data given in "g," to be used as covariates in the analysis); and (d) total absorbed power (a power measure used as a measure of frequency given in "Hz," used to measure one-third octave band frequency and used as frequency data in the statistical analysis) (see Table 1 for example). Rationale for the above is given in the following sub-sections.

Table 1

Sample Vibratory Data Collection
(taken from a previous collection)

Description	rms	+Peak	-Peak	Absorbed power (watts)
(V) Station Seat No. 1	0.22	1.02	-0.95	1.31
(T) Station Seat No. 1	0.19	0.73	-0.80	3.12
(L) Station Seat No. 1	0.29	0.99	-1.07	1.06

Human Vibration

Human vibration is classified basically by two general categories: *segmental* (hand-arm), which is vibration locally applied to specific body parts such as hands and arms as would be from a vibrating hand tool, and two forms of *whole body*, which are produced as the result of shock waves or vibration transmitted throughout the entire body (resonance) through some support such as a vehicle seat or floor. For the purposes of this experiment (riding while seated within a track vehicle), the latter was considered. The term resonance is used in human vibration research as the tendency of the human body to act in concert with externally generated vibration, actually amplify the incoming vibration (exacerbating its effect in the region of 4 to 8 Hz, particularly at 5 Hz [or in cycles per second], throughout a human's "whole body" although mostly within the upper torso). This is recorded in the vertical (*z*), horizontal (*x*), and lateral axes (*y*) (see Figure 3).

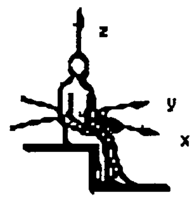


Figure 3. The three axes of movement upon which vibration measures are recorded.

Whole-Body Vibration

Although the chronic effects of whole-body vibration are not adequately known, short-term human and animal studies have shown that whole-body vibration may be regarded as a "generalized stressor," affecting multiple body parts and organs, depending on the vibratory spectrum and its relationship to various human resonance (particularly 5 Hz). Examples of laboratory studies with human subjects (Guinard, 1972) have shown that during whole-body vibration, increased oxygen consumption and pulmonary activity, hypoglycemia, gastrointestinal tract changes, and changes in nerve conduction may occur.

Whole-Body Vibration Measurement

Whole-body vibration is measured with respect to the standard biodynamic coordinate system according to International Standards Organization (ISO) 2631/1-1985E ("Guide for the Evaluation of Human Exposure to Whole-Body Vibration"). The frequency range of interest for whole-body measurement is generally 1 to 80 Hz, although it may be necessary to record frequency response below 1 Hz in certain applications (down to 0.05 Hz for some heavy equipment and for ship motion). For practical purposes, the 1- to 80-Hz response range is desirable because this allows accelerometer amplifiers to raise the signal level to a point where it can be accurately recorded. Measurements are made at identifiable parts of the body such as the buttocks or mounted on desirable bony protrusions while the subject is seated on (in contact with) a hard rubber disk. In the center of this disk, three perpendicular lightweight piezo-resistive accelerometers are placed.

Ride Quality Analysis

Two types of *ride quality* analysis are commonly performed. The first technique involves integrating power spectral density (PSD) data over frequency bands corresponding with those in ISO Standard 2631/1-1985(E). This PSD integration is performed to simulate what is normally accomplished by one-third octave band filters (analog or digital). The second commonly used technique requires determining the power absorbed by the subject seated at the monitored position.

The ISO standard considers the frequency range from 1 to 80 Hz, defining numerical limits for exposure to vibrations in that range in terms of weighted root mean square *(rms)* accelerations (weighted to account for resonance in the human body). The ISO defines its limits in terms of three criteria: *reduced comfort boundary*, *fatigue-decreased proficiency boundary*, and *exposure limit boundary*. The *reduced comfort boundary* represents the amount of time a subject could be exposed to the vibration level before feeling uncomfortable, without compromising performance or safety. The *fatigue-decreased proficiency boundary* is the amount of time a subject may be exposed to the vibration environment before his or her ability to perform a task is affected. The *exposure limit boundary* is the amount of exposure time allowed before the environment becomes unsafe or unhealthy. Exposure limit values are obtained by dividing the measured *rms* acceleration values by two and comparing these to a standard curve.

The method used to assess the three directional criteria is to separately compare each *rms* acceleration level for one-third octave bands of specified center frequencies against the recommended level at each frequency. A standard curve for the vertical axis is used, with one-third octave *rms* acceleration values from a given table. The time limit is taken as the minimum time for any of the one-third octave values. An ensuing method of evaluating the criteria, simulating a "Society of Automotive Engineer" (SAE) ride quality meter, involves weighting the values in the frequency domain with a curve that simulates the shape of the sensitivity curve for the given axis, thus producing an overall weighted *rms* value. This value is then compared to the most sensitive part of the standard (the 4- to 8-Hz band in the vertical direction, and the 1- to 2-Hz band at the other axes), and exposure times are determined. The permissible exposure time is then computed from the weighted *rms* acceleration.

The second measurement technique requires measuring the rate at which vibration energy is absorbed by the human body. Pradko and Lee (1987) established absorbed power in watts as a desirable quantity for expressing human tolerance to vibration. They studied vibrations in the frequency range of 0.1 to 12.0 Hz and made measurements at the buttocks in the vertical, longitudinal, and transverse directions along with vertical input to the feet of a seated person. Transfer functions were computed from the measured data (acceleration, force, and velocity) to convert measurements of acceleration to the power absorbed by the test subject. Absorbed power for a given location and axis is computed by multiplying the applicable acceleration power spectral density spectrum by the transfer function and then integrating the resultant spectrum.

The advantage of this approach is that average absorbed power is a scalar quantity and can be summed in multi-degree-of-freedom systems to yield a single value describing the total average absorbed power. This value can be used to develop criteria concerning the acceptability of various ride qualities. An upper limit of 6 to 10 watts' total absorbed power is generally accepted for the operation of off-road vehicles. A standard ride quality test procedure involves determining the speed at which the vertical absorbed power reaches 6 watts for different types of terrain. The vehicle speed (as a function of terrain roughness) obtained from this process is used as one of the mobility limiting factors. Ride quality requirements based on absorbed power in this fashion often appear in military vehicle specifications.

Both the ISO and the absorbed power method are frequency weighted to account for resonances in the human body. Although these factors result from independent methods, results appear remarkably similar. The actual weighting factors contain conversions from acceleration in *g*'s to feet per second and from acceleration to power in watts (based on the human body transfer function). To assist in understanding, the reader may find the following definitions for terms commonly used in reporting the measurement of vibration helpful.

Definitions Associated With Vibration Measurement

- *Vibration* is the variation with time of the magnitude of a quantity that describes the motion position of a mechanical system when the magnitude is alternately greater and smaller than the average value or reference.
- *Periodic vibration* is a periodic quantity whose values recur for certain equal increments of the independent variable.
- *Random vibration* is a vibration whose magnitude cannot be precisely predicted for any given increment of time. The probability that the magnitude of a random vibration falls within a given range can be specified by a *probability distribution function.*
- The *fundamental period* (of vibration) is the smallest increment of the independent variable of a periodic quantity for which the function repeats itself. The unit of frequency measurement is *hertz* (Hz), which corresponds to 1 cycle per second.
- *Peak value-peak magnitude-positive peak value-negative peak value* are the maximum values to quantify during a given interval. A *peak value* of an oscillating quantity is usually taken as the maximum deviation of that quantity from the mean value.
- A *positive peak* value is the maximum positive deviation, and a *negative peak* value is the maximum negative deviation.
- The *reference frame* is usually a set of axes at a mean position(s) of interest.

• *Displacement-relative displacement* is a vector quantity that specifies the change of positioned body or particle with respect to a reference frame. The *displacement* can be represented by a rotation vector, a translation vector, or both. A *displacement* is designated as *relative displacement* if it is measured with respect to a reference frame other than the primary reference frame designated in the given case. The *relative displacement between two points* is the vector difference between the displacement of the two points.
• *Velocity-relative velocity* is a vector that specifies the time derivative of displacement.

Vibration Data Verification

For this study, data verification was done in two stages: at the test site terminal during the acquisition process and at one of the analysis nodes during the post-test data analysis phase. The test site terminal verification process was designed to run from the computer alone (without a vector accelerator or array processor) and to function as quickly as possible to allow the acquisition process to proceed at a reasonable rate with some assurance that valid data were being collected.

The initial data verification that was performed consisted of searching the individual channels for frame errors and DC shifts using the program "*freer*." A frame error occurs whenever the PCM stream is interrupted, which induces artificial high-level spikes into the data stream. Data approaching full scale values, in addition to frame errors, were flagged by the frame error check program, because the program defines a frame error as being any data value that is greater than 98% of full scale. The same program checked the data for wild points and DC shifts. The magnitude of the change required to trigger a wild point error is operator selectable and was chosen as 100 computer counts for this project. A DC shift occurs whenever the data average changes rather abruptly and then remains constant after the change. The program defines a DC shift as a shift of more than 25 resolution steps from the previous average, with the average being based on approximately 1/6 second. A check was also made for incomplete frames of data (missing channels). These errors are obvious when plotted in the form of a time history, but the quantity of data collected is such that viewing it all as a time history is impossible. For this reason, the frame error check program was used, and locations of all such errors on the system disk were printed for a permanent record.

As a further step in the data verification process, acceleration amplitude distribution data were compiled by histogramming the data into a 512-bin field and calculating cumulative distributions using the program "*amdst*." Table 2 shows sample acceleration amplitude distribution data. The average value for each channel was removed to account for DC offsets in the instrumentation. The percentile columns represent the percentage of time the data fell below (plus) or above (minus) that particular value. For example, 99.9% of the time, the data value for Channel 1 was less than 1.02. The units for the accelerometer amplitude distribution data are in "g's."

Table 2

Sample Amplitude Distribution Data

Description	rms	+Peak	-Peak	+99.9%	-99.9%	+99%	-99%	+90%	-90%
Channel 1	0.28	1.25	-1.05	1.02	-0.71	0.68	-0.55	0.37	-0.36
Channel 2	0.31	1.32	-1.02	1.08	-0.78	0.71	-0.62	0.39	-0.42
Channel 3	0.23	1.34	-0.83	0.96	-0.65	0.66	-0.50	0.29	-0.27
Channel 4	0.22	1.22	-0.82	0.94	-0.58	0.62	-0.42	0.26	-0.26
Channel 5	0.24	1.04	-1.02	0.85	-0.64	0.59	-0.49	0.33	-0.31
Channel 6	0.36	1.50	-1.57	1.19	-0.92	0.81	-0.73	0.46	-0.46
Channel 7	0.39	1.66	-1.37	1.30	-0.97	0.86	-0.81	0.50	-0.49
Channel 8	0.21	1.27	-0.83	0.95	-0.60	0.64	-0.44	0.24	-0.24

The program that performed the amplitude distribution analysis and created tables also performed a number of data validity tests for each channel and provided messages such as (a) channel inactive (rms less than 0.03 g); (b) data one sided (+peak or -peak greater than 3 or less than one-third); (c) data noisy (99.9% or 90% [+ or -]) is greater than 4.82, which is twice the value for normally distributed data); (d) large kurtosis predicted (indicative of wild points; predicts kurtosis based on ratio of the actual 99.9% value to the expected [Gaussian] value and triggers when the prediction is greater than 5); (e) data clipped (peak value [+ or -]) exceeds 95% of full scale value); (f) large rms value (rms greater than 3.5 g); (g) large DC offset (average value is greater than 10% of full scale); (h) no data spread (lack of resolution), triggered if the 99% and 90% value (+ or -) are equal, or if the 99% range (+99% to -99%) covers less than 25 histogram bins; (i) shock present in the data (peak [+ or -]) greater than 6 times the rms value); and (j) discontinuous function (more than five empty bins from the first bin used to the last bin used).

Power Spectral Density Analysis

The acceleration PSD was computed by dividing the time domain data into a block of 2,048 points, converting to the frequency domain using the fast Fourier transform (FFT), and multiplying this result by its complex conjugate. The number of linear averages applied depended on the shock pulse duration. For a linearly averaged process, the number of statistical degrees of freedom is equal to twice the number of averages used. The amount of averaging (degrees of freedom) determines the degree of confidence that the value measured is a true representation of the actual physical phenomena. An error band, based on the number of averages, can be computed for various confidence levels from the chi-squared or degrees-of-freedom distribution.

Although the averaging process is unaffected by the data sample rate, the rate has an enormous effect on the resolution and validity of the PSD. The data must be sampled at a rate sufficient to prevent aliasing, yet slowly enough to provide adequate frequency domain resolution. Aliasing is a misrepresentation of the nature of the data because of under-sampling (sampling too slowly for the true frequency content of the data) and is corrected by low-pass filtering of the data and sampling at some rate above the filter cut-off frequency. The sampling ratio (sampling rate to cut-off frequency) depends on the type of filter used and knowledge of the frequency content of the data (the filtering effect supplied by the transducer). A sampling ratio of 4:1 is adequate for the filters used in the signal-conditioning package. While increasing the sample rate reduces the aliasing problem, the resolution problem is adversely affected by this action. The following time-frequency equations, based on the mathematics of the Fourier transform, describe the relationship between the sample rate and the frequency domain resolution.

$$T = BS / SR$$
$$F_{max} = SR / 2$$
$$\Delta f = 1 / T = SR / BS$$

in which

T	= Time to fill one analysis data block (N points), seconds.
BS	= Number of points in analysis data block (2048 for this analysis).
SR	= Sample rate, samples per second.
F_{max}	= Maximum frequency that can be represented by the data, Hz.
Δf	= Frequency resolution, Hz.

When the FFT algorithm is used, an assumption is made that the time record being transformed (data block) is repeated throughout time. If the time record contains an integer number of cycles within the data block, the assumption is valid and the waveform is said to be periodic within the time record. In most cases, the data are not periodic within the record, which causes a truncation of the signal at the end of the data block. Since the assumption is one of a repeated waveform, the analysis process assumes that the truncation is repeated throughout the entire data record. The effect in the time domain is an apparent discontinuity in the representation of the data signal. In the frequency domain, the discontinuity appears as side lobes or additional frequency components and is known as leakage. A time domain truncation technique known as windowing is employed to reduce the leakage. In addition to computing the linear average spectrum over the length of the data run, the program also computes the standard deviation at each spectral line and the peak value at each spectral line over the course of the run. At the conclusion of the process, the standard deviation is added to the average value and the average, average plus standard deviation, and the peak spectra for each data channel analyzed are saved in a file for further analysis.

NOISE MEASUREMENT

Noise levels were measured at the ear, using a microscopic microphone implanted in a hollowed ear plug (to allow transmission of voice instructions) and by microphone on tripod for interior ambient acoustics. The rationale for the former method is that the sound level at the test participant's ear (that which may cause human performance degradation) is paramount. Although much vehicular engine noise would be masked by the protective helmet (with ear cups) worn by participants, additional noise was introduced in the form of radio static through this headgear. The microphone was connected to a splitter-amplifier box, which in turn was connected to Aberdeen Test Center (ATC) recording equipment. In this way, *noise data* could be synchronized with *vibration data*. Also, in this manner, voice time stamps could be sent to the vibration recorder verbally by the experimenter to time correlate cognitive test phases with vibration data, since the vibration collection apparatus could not physically be connected to the computers on which cognitive tests were administered.

Materials

The Cognitive Test Batteries

The Criterion Task Set (CTS) [adapted from the *CTS Users Guide and Testing Manual*, IBM Version 2.0]

The original Criterion Task Set (CTS) is a battery of tasks developed by Shingledecker, Crabtree, and Acton (1982) to provide an instrument for human performance assessment, based in current theoretical models of perceptual motor and cognitive behavior. The component tasks of the CTS were designed to place selective demands on the functional information processing resources of the human operator. These elementary resources are hypothesized to be major determinants of a variety of complex task behaviors that occur in military and civilian work environments. To ensure that the CTS a usable and valid applied research tool, investigations were conducted at the U.S. Air Force Aerospace Medical Research Laboratory (AFAMRL) to standardize training requirements, task parameters, and loading levels.

In general, each CTS task includes three conditions which can be selected by the experimenter to produce low, moderate, and high levels of task demand. However, no rigorous inferences can be made concerning the absolute magnitude of the differences in task demand between low and moderate loads or moderate and high loads. In addition, for both theoretical and statistical reasons, it is asked that common loading levels on different tasks not be interpreted as being equated on any scale of measurement.

The CTS was designed to place highly selective demands on individual mental functions. Since time pressure is a generalized loading factor that affects workload in many functions, task pacing was not used to produce explicit variations in the demand of the CTS tasks. Thus, training in all tasks is conducted during essentially subject-paced conditions. Test trials are also subject paced but impose mildly restrictive time limits on the test participants' response in order to maintain trained performance levels. In all discrete stimulus tasks of the CTS, a response deadline is defined for each loading level. If the test participant fails to respond before the deadline, a new stimulus is automatically presented and the item is scored as a missed response. The deadline conditions for each loading level within each task were established by calculating mean reaction times for trained test participants and by adding three standard deviations of the mean to that value.

In all CTS tasks, a single test trial at any level of loading has a standardized duration of 3 minutes or less. The CTS tasks selected for the current exercise were as follow:

Continuous Recall Task [Tested Resource/Function: Working Memory Encoding] [Typical Resource Based Behaviors: Memorizing, Keeping Track of Events]

The CTS Continuous Recall task is a standardized loading task designed to place variable demands upon processing resources associated with encoding and storage in working memory. The task requires an operator to use both immediate and short-term memory of numbers during continuously changing storage states. The memory test consists of a random series of visual presentations of numbers which the operator must encode in a sequential fashion. As each number in the series is presented for encoding, a probe number is presented simultaneously. The operator must compare this probe number to a previously presented item given at a pre-specified number of positions back in the series. Once the operator has made the appropriate recall, he or she must decide if that item is the same or different than the probe number. Thus, the task exercises working memory functions by requiring operators to accurately maintain, update, and access or store information on a continuous basis. Task difficulty is manipulated by varying the number of digits that comprise each item and by the length of the series that must be maintained in memory in order to respond to recall probes.

Loading Conditions Research conducted has shown that three significantly different task demand levels are produced by the following conditions: low demand, one digit per item, recalling one position back; medium demand, two digits per item, recalling two positions back; and high demand, four digits per item, recalling three positions back.

Stimuli Computer-generated one-, two-, and four-digit numbers are displayed serially on a cathode ray tube (CRT) screen with the following restrictions: (a) test numbers must be randomly generated; (b) only the numerals 1 through 9 are used; (c) roughly half of the probe numbers must result in a recall comparison of "same." Test numbers and probe numbers are simultaneously presented, as well as terminated. The test numbers always appear below a line centered on the CRT, while the probe numbers appear directly above the line.

Testing Procedure Major practice effects are eliminated with five 3-minute trials at each loading level. However, the extension of training to seven trials produces more stable performance. Test participants are encouraged to respond as rapidly and accurately as possible. In all conditions, the task is subject paced within the limits of selected deadline reaction times. Maximum acceptable reaction time in the training mode is definable by the experimenter for all conditions. If the test participants do not respond within this time after the onset of the test item, the next item is automatically presented. In the testing mode, the reaction time deadlines are reduced: 1.1 seconds for the one digit, one back condition; 1.7 seconds for two digits, two back; and 2.3 seconds for four digits, three back. The numbers display is approximately 1.25 inches high; each number is approximately 0.25 inch x 0.13 inch, and this should be viewed from a distance of roughly 60 centimeters.

Mathematical Processing Task [Tested Resource/Function: Spatial Information Manipulating] [Typical Resource Based Behaviors: Computing, Calculating, Comparing Values]

The CTS Mathematical Processing task is a standardized loading task designed to place variable demands on information processing resources associated with the manipulation and comparison of numeric stimuli. The task requires the test participant to perform one or more simple arithmetic operations on visually presented, single digit numbers to determine whether the correct answer is greater or less than a pre-specified value (10). Task complexity is determined by the number and combination of operations in the problems.

Research has shown that three significantly different task demand levels are produced by the following conditions: (a) operator problems involving either addition or subtraction (low demand); (b) operator problems with + -, - +, and - - operator combinations (moderate demand); and (c) operator problems with + + -, + - -, and - + - operator combinations (high demand).

Stimuli Math problems requiring simple addition and subtraction are randomly generated with the following restrictions: (a) only numbers 0 to 9 may be used in the problems; (b) the correct answer may be any number except 10;(c) roughly half of the problems must have an answer greater than 10; and (d) successively presented problems never have the same combination of numbers and operations in the same order and are therefore never identical.

Testing Procedure The amount of practice required to reduce the effect of training to nonsignificant levels depends on the number of operators experiencing the problem. One-operator problems require seven training trials while two- and three-operator problems require 10 training trials. Performance stability is enhanced if practice is extended to 14 and 30 trials, respectively, for the two- and three-operator conditions. Test participants should be instructed to perform the operations from left to right in order to avoid calculations with negative numbers. Response deadlines of varying length are imposed so that test participants can pace themselves within certain experimenter-determined limits. If a response is not made within the deadline time, the stimulus is erased and a new one presented. Test participants respond by pressing one of two appropriate keys. Measures of reaction time and percent correct are taken.

Grammatical Reasoning Task [Tested Resource/Function: Reasoning] [Typical Resource Based Behaviors: Problem Solving, Analyzing Relationships, Logical Thinking]

The CTS Grammatical Reasoning Task is designed to impose variable processing demands on resources required for logical thought. The logical system contained within English grammar is used to test the ability to extract relational rules from sentence stimuli. The task was derived from Baddeley's (1981) Grammatical Reasoning Task. Stimulus items are sentences of varying syntactic structure accompanied by a set of symbols presented simultaneously. The sentences must be analyzed to determine whether they correctly describe the ordering symbols in the symbol set. Task demand is influenced by the amount and complexity of grammatical analysis. Testing has demonstrated that three different levels of grammatical demands are imposed by the following task conditions: (a) single sentence items of variable syntactic construction describing the order of pairs of letters (all possible stimuli in the Baddeley version), producing low demand; (b) items composed of two sentences worded actively and positively, and describing the positions of three symbols, causing moderate demand; and (c) two-sentence items worded either actively by negatively or passively by negatively and describing three symbols, causing high demand.

Stimuli The stimulus population for single sentence problems is comprised of all possible combinations (32) of the following five binary conditions: (a) active versus passive wording of sentences; (b) positive versus negative wording; (c) keyword "follows" versus "precedes"; (d) order of the two symbols in the sentence; and (e) order of symbols in the symbol set. For one-sentence (simple) items, the test participant's task is to decide whether the symbol set is ordered as the sentence indicates. In the task conditions using two sentences (medium and high demand conditions), the object is to determine whether bold sentences match in their correctives. If both sentences correctly describe the ordering of the three symbols or if either is correct, the test participant responds positively. If one sentence is correct but the other is not, a negative response is given. Sentences always describe adjacent symbol pairs and are of the same grammatical formula (in other words, an active by negative sentence is never paired with a passive by negative sentence). To help equate all conditions, problem sets of 32 (total number of single sentence problems) were randomly selected for the two-sentence conditions with two restrictions. First, when correctly solved, half of the two-sentence problems result in a positive response. Second, combinations of sentence answers (such as Sentence 1 true, Sentence 2 true; Sentence 1 true, Sentence 2 false, etc.) occur equally often. Equal numbers of active by negative and passive by negative items are used in the high demand condition.

Testing Procedure Major practice effects are eliminated with nine training trials at each loading level. Binary responses are entered manually on appropriate keys.

Sternberg's Memory Search Task [Tested Resource/Function: Working Memory Retrieval] [Typical Resource Based Behaviors: Recalling Recent Events]

The CTS Memory Search Task, based on Sternberg's (1977) memory search paradigm, is a standardized task designed to place variable demands on human information processing resources dedicated to short-term memory retrieval functions. In the memory search task, a small set of items (the "memory set") is first presented to the test participants for memorization. A series of test items is then presented to the test participants one at a time, and the participants must respond positively if the test item was contained in the memory set (or negatively if not). Reaction time is measured from the onset of the test item to the response. The CTS version of this task is composed of a variable number of demand levels produced by variations in the number of items to be memorized.

Stimuli Stimulus items in the CTS memory search task are visually presented alphabetic characters. Memory set items are randomly selected from the letter population, and the remaining items are used in the negative set. A new memory set is selected at the beginning of each trial. Test items are also randomly generated with the restriction that positive and negative set items are drawn with equal probability.

Testing Procedure Major practice effects are eliminated with seven training trials at each loading level. However, extension of training to 16 trials produces more stable performance of the memory search task. Participants are encouraged to respond as rapidly and accurately as possible. In all conditions, the task is subject paced with a deadline, allowing test participants to pace themselves within the experimenter-determined time constraints. Maximum acceptable reaction times in the training mode are definable by the experimenter. If the test participant does not respond within this time, the next item is automatically presented. In the testing mode, reaction time deadlines are reduced: 1.5 seconds for memory set size one, 2.0 seconds for set size four, and 2.5 seconds for set size six. Letters are approximately 0.5 x 0.7 centimeters and should be viewed from a distance of roughly 60 centimeters. Responses are entered on appropriately labeled keys.

The Complex Cognitive Assessment Battery (CCAB) [adapted from the *CCAB Test Descriptions Manual*, MDA 903-84-C0449]

The computer-based Complex Cognitive Assessment Battery (CCAB) originated as a battery of tests for use in the assessment of the effects of drugs on complex cognitive performance, required military tasks such as Army command and control (C^2) and operational tasks. Assignment of capabilities to categories is said to be based on logical analysis rather than on empirical data, such as measures of secondary task performance. These concepts have received extensive treatment in psychological literature (Moray, 1967; Norman, 1983; Sanders, 1979), and are considered valid.

Route Planning [Tested Resource/Function: Perception of Form, Concept Formation, Quantitative Reasoning] [Typical Resource Based Behaviors: Planning, Situation Assessment, Decision Making, Problem Solving]

The purpose of the Route Planning Test is to measure the test participants' ability to plan and execute a route from a starting position to an ending (target) position. The test participant must apply simple rules of movement and with a variety of movement constraints. This test was included in the CCAB primarily to measure the cognitive functions of planning. Secondarily, the Route Planning Test assesses perception of form, situation assessment, communication, and problem solving performance. In addition, this test measures aspects of attention to detail, comprehension, quantitative reasoning, and decision making. Almost every complex task includes planning as a component process. Thus, an understanding of the cognitive processes involved in planning has practical as well as theoretical significance. While a few studies have investigated planning, per se (Hayes-Roth & Hayes-Roth, 1979; Sacerdoti, 1974), several experiments have focused on individual differences in problem solving processes, which are relevant to planning (Chase & Simon, 1973; Newell & Simon, 1972). This work has shown that the problem solving approaches or strategies of experts differ from those of novices. For example, Simon and Simon (1978) found that experts tend to work forward from the problem given while novices work backward from goals. With a map learning task, Thorndyke and Stasz (1980) found several procedures for focusing attention and encoding map information, which distinguished good from poor map learners. Furthermore, these procedures could be learned by novices to improve performance.

Stimuli The test participant is presented with a 5 by 5 matrix (25 squares), with 11 squares shaded as determined by pseudo random selection. The remaining unshaded squares display 14 letters of the alphabet. Since the matrix contains 25 squares, all letters of the alphabet, except for the letter "Z," could be displayed. However, the 11 shaded squares hide 11 of the letters so that only 14 letters are visible at any given time. The letters are ordered from left to right in the matrix, with the top left square containing the letter "A," and the bottom right square of the last row containing the letter "Y."

Testing Procedure The test participants' task is to get from a designated starting square to a designated ending square by planning and communicating a route. Although test participants can traverse the shaded squares, they cannot land on them. A trial ends when the ending square is reached or when the allotted time (either 60, 90, or 120 seconds as predetermined by the experimenter) has elapsed.

Missing Items [Tested Resource/Function: Attention to Detail, Concept Formation, Planning] [Typical Resource Based Behaviors: Situation Assessment, Problem Solving, Decision Making]

The purpose of the Missing Items Test is to measure the test participants' ability to identify missing items in a series of items. It is included in the CCAB primarily to measure the cognitive functions of concept formation and planning. Secondarily, the Missing Items Test assesses decision making and problem solving performance. In addition, this test measures aspects of attention to detail, situation assessment, communication, and creativity. A general paradigm for studying a concept formation behavior model was developed by Bruner, Goodnow, and Austin (1956). They examined two methods for presenting positive and negative instances of a given concept to test participants, one in which the instances are randomly presented with feedback, and one in which the instances are selected by the test participant with feedback. A strategy can be inferred from the pattern of decisions made by a problem solver seeking to discover a concept.

Bruner et al. (1956) noted two distinct solution strategies. The *wholist* strategy depicts a test participant who remembers all the attributes common to positive instances and ignores everything else, thus eliminating attributes that are not part of a positive instance. The *partist* strategy depicts a test participant who focuses on one attribute at a time, keeping the hypothesis if it correctly predicts the membership of an instance and forming a new hypothesis if it does not. As related to letter patterns presented in the Missing Item test, the *wholist* strategist would most likely try to assess both the letter case <u>and</u> letter pattern simultaneously, whereas the *partist* strategist would attempt to assess the letter case and letter patterns separately. In general, Bruner found that the *wholist* strategy resulted in better learning, especially when test participants were under time pressure. These strategies are similar to the "focusing" and "tactical" selection strategies identified by Laughlin, Lange, and Adamopoulous (1982). The term "focusing" can be associated with the *wholist* strategy, and the tactical strategy with the *partists*. Laughlin et al. (1982) found that these two selection strategies were characterized by marked differences in cognitive demand requirements, particularly with regard to inference and insight capabilities. Although the focusing strategy made fewer cognitive demands than did the tactical strategy, it was found to be correspondingly less efficient as a solution strategy.

<u>Stimuli</u> Following the practice trials, the test participant was presented with a series of true or false questions on a CRT display, practiced earlier to ensure that the test participant understood the task.

<u>Testing Procedure</u> Instructions were presented via a CRT display and included a simulated solution to a typical Missing Items problem.

Test instructions, given orally to test participants before each test, were as follow:

1. For the "Recall" test, "On one screen, you will be shown one number on top of another. On the next screen that comes up, you'll again be shown one number on top of another, but here you must tell if the bottom number from the last screen (the previous screen) you looked at is the <u>same or is different</u> from the top number of the screen

you are looking at. If it's the same, say so by pressing the 'F' (red) key. If it's different, press the 'J' (yellow) key."

2. For the "Math" test, "You'll be given a math problem to figure out and will be asked to say if the answer is greater or less than 10. If the answer is greater than 10, press the 'F' (red) key. If the answer is less than 10, press the 'J' (yellow) key."

3. For the "Reasoning" test, "You'll be shown two figures on the same screen, one after another, such as * @. Then you'll be given a sentence such as ' * precedes @' and will be asked if this is correct or not. If this statement is correct, press the 'F' (red) key. If it isn't correct, press the 'J' (yellow) key."

4. For the "Memory" (Sternberg) test, "You will be shown a list of letters and asked to memorize them. On the following screens, you'll be shown just one letter and asked if this letter was in the original set of letters that you were asked to remember. If it was one of the original letters, say so by pressing the 'F' (red) key. If it wasn't one of the original letters, press the 'J' (yellow) key."

5. For the "Route Planning" test, "You will be asked to get from one specified letter to another but only by making jumps of either two letters in one direction and one in another direction, or one letter in one direction and two in another direction (picture making moves in the shape of the letter 'L'). You may make moves by pressing the letter you wish to go to or by using the arrow (cursor) keys."

6. For the "Missing Items" test, "On screen you will be shown a series of either numbers or letters, but with one of these in a logical string missing. Below this, you will be asked to select, from a number of answers, which number or letter is missing from the set given on the top of the screen. When selecting letters, be sure to consider whether you need to choose a capital letter or a lower case one. When you decide what letter or number answer you want, use the arrow (cursor) keys to get to it, and then press the 'enter' key."

The Stress Assessment Battery

The following battery of stress-related questionnaires was presented to test participants in order to elicit subjective responses to present state of

Logical Reasoning Task [Tested Resource/Function: Inductive Reasoning]

For the Logical Reasoning Task, participants were asked to read lists of short statements such as "S follows T," with a response following each statement such as "ST" or "TS." Participants are to decide, by circling "true" or "false," whether the two-letter response is correct. Here, they are given 1 minute to complete a list of 32 statements [U.S. Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD].

Multiple Affect Adjective Checklist-Revised (MAACL-R) [tested resource/function: current attitude]

The Multiple Affect Adjective Checklist - Revised (MAACL-R) is a test that asks participants to describe their current mood, selecting from a list of 132 adjectives such as "adventurous," "good-natured," and "thoughtful" (Zuckerman & Lubin, 1985) [M. Zuckerman & B. Lubin, "EDITS" Publishing, San Diego, CA].

Word Recall Task [Tested Resource/Function: Short-Term Memory]

In the Word Recall Task, the test participant was given a list of 12 words to memorize and allowed one practice session of rewriting each. The list of words is then taken away, and the participant given 1 minute to recall (in writing) as many words from the list as can be remembered (Baddeley, 1968) [U.S. Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD].

Stanford Sleepiness Scale [Tested Resource/Function: Physical Fatigue]

For this, the test participant was asked to state how sleepy or awake he or she currently felt, by selecting from a list of seven statements comprised of adjectives such as "alert," "foggy," and "responsive" (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) [Adaptation by U.S. Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD].

Environmental Symptoms Questionnaire [Tested Resource/Function: Mental Fatigue]

The test participant was given a list of symptom statements such as "I feel weak" or "I am bored" and was then asked to indicate whether he or she currently experienced any of these symptoms (Sampson & Kobrick, 1980). For the present field exercise, only the "Fatigue Items" from this questionnaire were asked. [This questionnaire was modified by U.S. Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD.]

Continuous Recall Task [Tested Resource/Function: Working Memory Encoding]

The test participants were presented numbers on paper, resembling a mathematical division equation where two numbers are placed over two others. They were to memorize the bottom two numbers. This was taken away and they were then given a similar set of numbers and asked to recall if the top two numbers on this new sheet are the same or different from the bottom two numbers on the previous sheet given. Response time is limited by time restraints. Although the same test was given on computer during the driving and stationary conditions, this test was repeated to allow comparison between moving with on-screen stimuli and paper and pencil administration.

Amylase Assay

This experiment was an attempt to gain insight to the degree of environmental effects on observed cognitive processes during moving operations. As such, the "stress battery" (developed by researchers at the Army Research Laboratory's Human Research and Engineering Directorate) was included to address test participants' physical and emotional wellness during operation in hopes of determining cognitive performance degradation (if observed) which may be attributed to this phenomenon. One measurable result of induced stress in humans is an increase in the secretion of salivary amylase. Amylase is an enzyme that hydrolyzes starch to oligosaccharides and, in turn, slowly to maltose and glucose. The "Field Assay for Amylase" is a method for measuring the degree of this enzyme produced, assessing human stress by measuring a chemical change in bodily fluid (Blewett, Redmond, Cadarette, Hudgens, & McKiernan, 1994; Hudgens, Malkin, & Fatkin, 1992). Measurement of amylase in saliva involves chemical color changes according to standard photometric procedures developed by Northwestern University.

Saliva samples were obtained from participants by providing them small, clean rectangular sponges (1 in. x 0.5 in. x 0.5 in.) in plastic "zip-lock" bags. Participants were instructed to roll the sponges in their mouths for 1 minute, then deposit the sponges back into the plastic bag. A monitor collected the bags from the participants and refrigerated them until the amylase assay was completed.

Saliva samples for amylase assay were collected from the participants on nine occasions. The schedule for administering measures was as follows: (a) baseline measure, once before training and initial cognitive test administration (first assay); (b) pre-measure, once before the morning's first cognitive test battery administration, while stationary (second assay), and (c) during measures, once <u>each</u> after completion of the six cognitive test batteries (third through ninth assay). Note. To minimize the risk of amylase sponges being swallowed, the vehicle was not moving at any time while participants were administered the sponges (as they placed them in and shifted them inside their mouths) to collect saliva.

The MACS Vehicle

Because of financial and scheduling constraints, the prototype C^2V was not available. Given this, a modified M113 tracked vehicle, previously referred to within ARL as the mobile armor crew station simulator (MACS), was used (see Figure 4). Though the prototype C^2V allows for four operator terminal stations plus additional crew, the available M113 houses only two operator terminal areas with room remaining for the driver and one observer (see Figure 5). Seats for test participants were those used in the Bio-Integrated Detection System (BIDS), approved by the Surgeon General. These are cushioned and adjustable high-back seats, similar to the operator seating installed in the prototype C^2V.

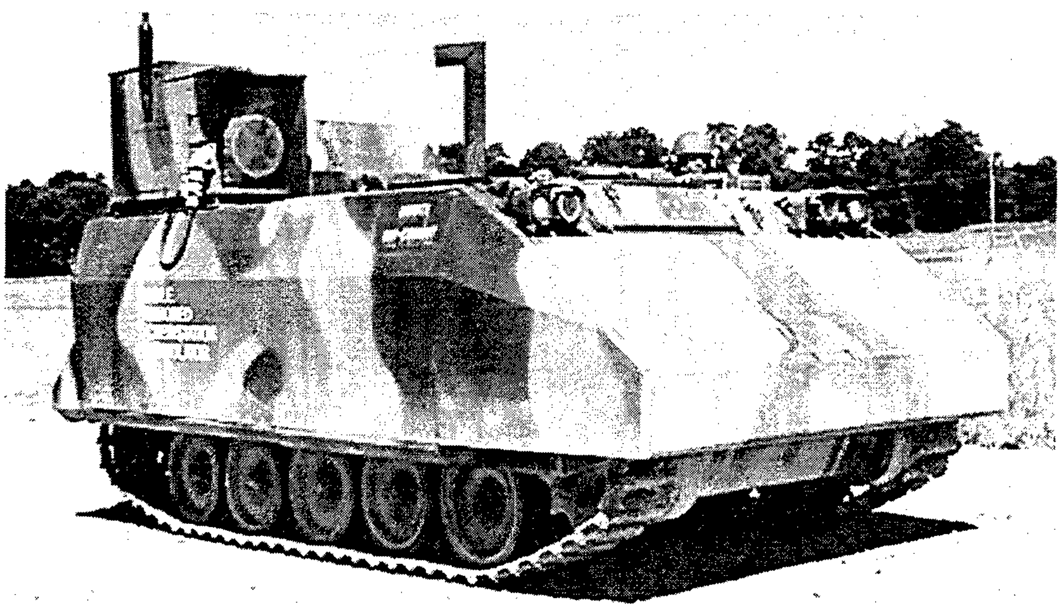


Figure 4. The mobile armor crew station simulator (MACS) vehicle, a modified M113 armored personnel carrier.

Seats were secured at a height of approximately 11.5 inches from the vehicle floor, and cushion thickness was 4 inches at the seat bottom and 3.5 inches at the seat back. Seat restraints were lap-type adjustable, 2-inch web, item number 2540-01-203-0183, routinely issued with Army APCs.

Interior lighting level, recorded at computer monitor, measured 500 footcandles (f.c.). At test participant facial area, light level was recorded at 130 f.c. A light meter was used.

The lighting was one fixture, housing two incandescent 28-volt 50-watt bulbs, centered on the vehicle ceiling, mounted over and slightly behind test participants' heads. In this manner, no reflection on either computer screen was produced.

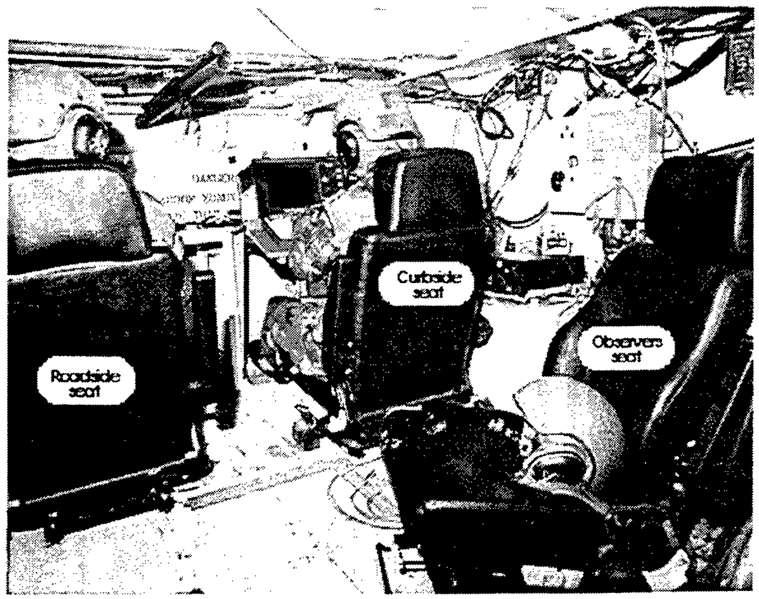


Figure 5. Test participants' and observer seating positions in the MACS vehicle.

Interior temperature was maintained at a range of 67° to 73° (F) by a combined electronic cooling and heating unit installed into the modified rear top hatch of the vehicle. The fan of this unit produced average air flow of 29.83 feet per minute, measured at the area between test participants' seats with a multipurpose Compflow meter model 8575. Air quality was measured routinely by ARL Risk Management Industrial Hygiene Branch personnel to assure compliance with operating regulations per Title 29 Code of Federal Regulations Part 1910.1000 (Air Contaminants), revised 1994, Occupational Safety and Health Administration (OSHA) general industry standards. Findings for sample oxides of nitrogen and nitrogen dioxide were 0.055 milligram per cubic meter (mg/m^3), which is well below the OSHA short-term exposure limit of 1.0 mg/m^3, and sample carbon monoxide found to be 12 parts per million (ppm), which is also below OSHA's permissible exposure limit of 35 ppm. During days of operation, exterior temperature ranged from 32.6° minimum to 76.8° maximum (F) with averages of 42.4° minimum to 65.2° maximum; average peak wind speed was recorded at 7.4 miles per hour, and average relative humidity was recorded at 88%, producing a wet bulb average of 58.27. Light drizzling rain was experienced sporadically during 3 days, only enough to measure an average of 0.86 inch over all days of operation. This small amount of rainfall did not influence track characteristics or operation (see Figure 6 displaying vehicle interior data collection apparatus).

Vibration Measurement Apparatus

Whole-body vibration was measured by the use of two ATC magnetic tape data acquisition systems composed of (a) transducers with specified ranges designed for full scale recording of $\pm$5G; (b) signal-conditioning electronic packages containing direct current for the transducers; and (c) shock-mounted tape recorders for recording the frequency-modulated data. If equipment or the funds for equipment had not been available, vibratory information (the 20-mph traverse level performed) would have been extrapolated from Report Number 95-LR(V)-81 “Safety Verification Test of the M113/BMP-2 Opposing Forces (OPFOR) Surrogate Vehicle (OSV) Whole Body Vibration”, 1995. This test, conducted by the U.S. Army ATC, reports on the measured vibration (in watts) of two vehicles using human test participants alternated with water-filled dummies, driven over ATC courses to include the test course proposed for this study (Cross-Country Course Number 2).

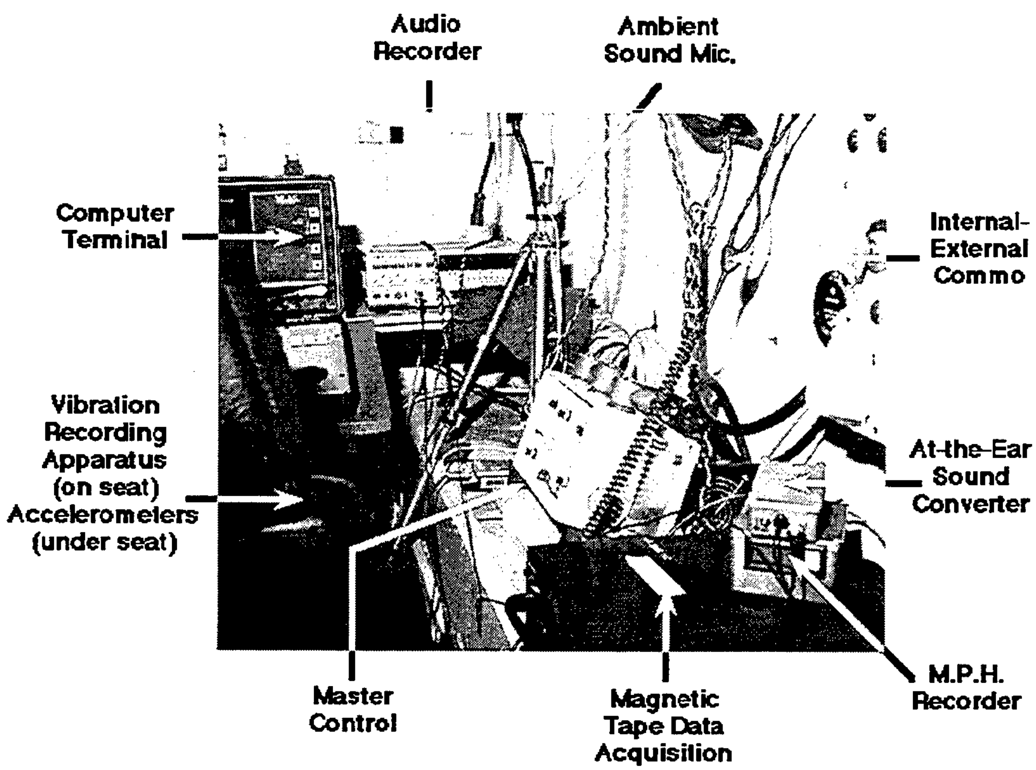


Figure 6. Interior data collection and communications apparatus housed within the interior of the MACS vehicle.

Driving Course

Perryman Test Area, approximately 2,000 acres located at the northwestern boundary of Aberdeen Proving Ground, was selected as best representative of an off-road and cross-country driving condition for tracked vehicles. This area is used mainly for durability and reliability testing of cross-country vehicles. Changes in course geometry (varying surface conditions because of weather) are assessed periodically by a test course committee, which recommends appropriate maintenance to restore the course to normal severity. Test course area supervisors also conduct daily inspections, maintaining on-site logs of climatic and course conditions. Details of these procedure are contained in Test Operations Procedure (TOP) 1-1-011 (TECOM, 1981).

Of the four cross-country loop courses at Perryman (each graduated in severity), Course 2 is laid out in a loop of moderately irregular terrain, the most desirable for this effort. Surfaces range from smooth to rough, with sweeping turns. During wet conditions, the course is said to be extremely muddy; when dry, it is extremely dusty. Potholes and sharper depressions are usually limited to a depth of 15 centimeters by back-filling with crushed stone. On observation, it was evident that this area allowed modified terrain roll and pitch, yet maintained true off-road conditions. Other courses in this area were rejected because of observable and documented extremely rough terrain, characterized by a succession of depressions that apparently developed after intensive operation by heavy track-laying vehicles (such as repetitive humps spaced in patterns, with horizontal distances from high to low averaging about 13.75 feet and vertical from low to high averaging about 12.5 feet) (adapted from TOP 1-1-011 [TECOM, 1981]).

Computer Workstations

The computers used for this field exercise were two Version 2 lightweight computer units (V2LC). These are ruggedized 25-MHz, 32-bit processor (with embedded floating point processor) 486 portable computers, running MS-DOS™ (which allows the use of IBM™ PCsPC applications). These possess a standard 8 MB of random access memory (RAM) and operate on standard 110 electrical power (with the option of using military vehicle power or a DC-AC inverter or battery charger). Each computer houses a 10-inch (measured diagonally) liquid crystal display screen (640 x 480), with a standard video graphics array (VGA) port for the addition of an external color monitor. The computers are equipped with detachable keyboards with embedded trackballs, and each has one floppy disk drive. The computers' dimensions are 9.5 inches high by 16.0 inches wide by 10.4 inches deep. The V2LC weighs 27.5 pounds and has been approved for use when withstanding normal military tracked vehicle vibration. Computers and detachable keyboards were secured to a table inside the vehicle by a combination of shock-mounting hardware and adjustable fasteners. In this manner, minimal vibration occurred at the monitor. Procedures for this have been established and are commonly applied by members of the ATC vibration measures group. In essence, monitors are bolted to the same structure as participant seats. Approximate distance from subject facial area to computer monitor ranged from 18 to 25 inches, depending upon individual seat adjustments made. These distances, combined with the angle at which monitors were affixed, produced (subtended) visual angles ranging from approximately 10° to 18°. Test participants sat with legs extended at a 30° angle, feet resting on foot rests.

To reduce the risk of test participant confusion in selecting response keys, computer keys used for this experiment were labeled and color coded. The "F" key was color coded *red* (to answer "yes" or "greater" to questions on parts of the CTS); the "J" key was color coded *yellow* (to answer "no" or "less-than" to questions on parts of the CTS); the "back slash" key was color coded *black* (to increase speed of the test observer when changing software from CTS to CCAB and reverse, since the former operates in MicroSoft Windows™ and the latter in DOS™); the "F4" key was color coded *black* (also to assist changing from CTS to CCAB software and reverse); the "Alt" key was color coded *black* (again to assist changing from CTS to CCAB software and reverse), and the "top right, third from the end" key on this keyboard was color coded *green* (since, when using the computer trackball, this key serves as the "return" key). Additional labels were made (white lettering on black backgrounds) and placed near appropriate keys to designate "Alt," "Ctl/Alt/Del," and "Alt/F4." All labels were made with a label gun, cut out, and pasted on or near appropriate keys. This schema was also followed for the desktop computers used during training.

Post-training Questionnaire

Questions were asked of test participants about the effectiveness of the pretraining given (if they understood their tasks), to elicit comments about the difficulty of the tests administered and about the quality of environment the test was conducted in, such as whether the test participants experienced physical problems (see Appendix B).

A Demographic Survey

Questions were asked of test participants, eliciting their previous experiences with tracked vehicles, in military command and control operations, and of physical disorders that might hamper their test performance (see Appendix C).

Noise Data Collection

Although noise measures were collected once while in the "moving" and once in the "stationary" condition at the ear to ensure that exposure limits were not exceeded, this effort presented the opportunity for the collection of data that may later be used for comparison among vehicles and environments. Thus, continuous noise measures were made to especially observe while the vehicle was (a) stationary, with all systems off; (b) stationary, with only the auxiliary generator running; (c) stationary, with only the engine running; (d) stationary, with both auxiliary generator and engine running (as this is normally the situation in tactical operations centers, it became the "stationary" condition used for analyses); (e) moving, with only the engine running, at four separate areas over the length of the track; and (f) moving, with both auxiliary generator and engine running, at four separate areas over the length of the track. No differences in sound levels in decibel, A-weighted (dBa) recordings between traversing separate areas of the track could be found; however, as speed increased, dBa increased.

Test Participants

A total of 18 military volunteers, ages 21 to 34, served as test participants. Of these, all were not assigned to ARL or to ATC. Medical profiles were reviewed before participant selection to eliminate persons with known physical ailments that might be exacerbated by participation. Participants were screened to be free of skeletal, cardiopulmonary, and other medical or psychological conditions that would preclude participation, and vision was checked to preclude anyone from becoming a participant who had less than 20/40 (corrected or uncorrected) vision.

Procedures

Daily Test Schedule

Participants were randomly assigned a test participant number for confidentiality purposes and received the experimental conditions according to a balanced experimental scenario. (Odd numbered test participants were assigned the roadside seat and even numbered participants the curbside; both groups of participants began their first test segment while stationary.) Each participated for only one day. During both moving and stationary conditions, testing was not initiated for the first 15 minutes of each segment to ensure participant acclimation to the vibration condition presented.

Test participants received each entire cognitive test battery eight times, during eight 40-minute segments, four while moving and four while stationary. Participants were tested until all stimuli were exhausted, proceeding through the experiment. Cognitive assessment stimuli were presented by computer, which was also the means by which responses were collected. Stress assessments, presented by paper and pen, were administered at logical intervals, once before testing, once after each test session, and again at the conclusion of the entire eight periods. The demographic survey was administered (verbally, by the experimenter) before test initiation, and the post-training questionnaire was administered (verbally, by the experimenter) at the conclusion of testing.

The provision made in case of participant attrition was that data from partial-day participant dropouts would be discarded, and every attempt possible was made to replace voids caused by this. Additionally, a divider (curtain) was placed in the vehicle between test participants to minimize the effect of one becoming ill and influencing the other, and the vehicle floor was sprayed with a liquid pine freshener each morning to alleviate odors caused by prior illness or vehicle fumes.

Training

Although test participants attended one training day (of approximately 5.5 hours) before actual participation, they were also trained (approximately for 1.5 hours) during and before testing. Training was conducted verbally and on screen per instructions supplied with individual cognitive tests and in accordance with proper techniques in the case of the stress assessment. On the one day of pretraining, participants experienced each test 6 to 12 times. During actual testing (before the administration of each test), participants were given the test instructions at least twice and were instructed to ask any questions they might have. Participants were trained to a criterion of 90% correct.

RISK ASSESSMENT

The only risks anticipated were those that may occur because of vehicular motion such as illness or by physically striking the interior of the vehicle. Test participants were briefed about possible risks before their participation; all questions were answered whenever presented during operation, and a volunteer agreement was signed by each participant before participation. Participants were also instructed to signal any available experimenter immediately upon the onset of illness or injury. All personnel riding in the vehicle wore the head protective gear "combat vehicle crew member" (CVC) helmet (DH132), incorporating capability for electronic interior communication. The head protection used, the armored vehicle crewman helmet model DH-132, offers impact protection with noise attenuation and communication capability. This helmet consists of a rigid outer protective shell attached to a separate inner liner by means of snap fasteners at the right and left temple areas and at the center of the back of the head and by Velcro® tape running from crown to the forehead area. The inner helmet consists of foam energy-absorbing sections enclosed in a Nomex® mesh fabric, with leather fastener mounts for attaching the outer shell and the chin strap. A rigid outer ear cup with foam padded inner seal earphone is inserted into openings in the Nomex® mesh of the inner liner. A microphone boom is attached to the right rigid ear cup. An earphone switch and the upper earphone cord are attached to the left cup. A retractable (coil spring type) cord, for plugging into the vehicle's communication system, is attached to one ear cup. The weight of each helmet is approximately 3.25 pounds.

Noise was measured at the ear to ensure that prolonged exposure limits (85 dB over 8 hours) were not exceeded, and radios were monitored inside and outside the vehicle by experimenters to maintain contact with medical support. Test participants were briefed about procedures to follow in case of illness. Air flow and temperature were maintained at a comfortable state inside the vehicle, and ambient lighting was measured to ensure visibility. Seat belts were worn at all times by all personnel within the vehicle, and participants were instructed about an orderly plan for escape through the rear of the vehicle in case of fire. Test participants were debriefed upon completion of their participation. Adherence to TOP 1-1-011 and associated standing operating procedures and safety assessments was enforced.

RESULTS

Data were captured by computer software, transferred to Microsoft Excel® version 5.0a for sorting, then input to StatView® version 4.5 for analysis. To assist in understanding the terms used, *endurance* refers to the amount of time spent in the vehicle (from 0 to approximately 450 minutes); *absorbed power* refers to the magnitude of vibration received by test participants; *exposure limit* refers to comparison of results with a table of accepted human performance criteria for limits of vibration; *session* refers to one of eight instances during which subjects were administered the battery of cognitive tests (at odd numbered sessions, participants received minimum vibration; at even numbered sessions, participants received either medium or maximum levels of vibration); and *noise* refers to the decibel (dBa) level experienced and measured at the ear. Further, *condition* refers to one of three speeds of travel condition (0, over 10, and over 20 miles per hour), which was the method for gaining vibrations. Results are reported for two dependent variables, percent correct (the percentage of answers responded to correctly by subjects), and time taken (the percentage of time taken for subjects to answer questions, of the time allowed for answers).

The rationale for the following analysis was to quantify possible changes in specified human cognitive processes, which may be attributable to vehicular vibration over time. In doing so, the psychometrics applied were evaluated. This was a "between" (motion versus stationary) and "within" subject (test battery) design. *A priori* contrasts were used to test for changes in test participants' test scores across sitting and riding conditions, as well as between sitting and riding conditions. Specifically, a multiple comparison procedure for multiple (paired) comparison tests was used (Sidak, 1967).

Although the moving versus stationary conditions were compared individually (to determine differences) and collectively (to assess overall effect because of exposure), these were not related to results of a data collection taken in a classroom setting during test participant training, as the situation of interest was participant performance *in the vehicle*. Rather, results were compared to "baseline" performance at Session Number 1 of testing. Trend analysis (to determine the slope, ascertaining linear and quadratic trends in the data) will eventually be performed, enabling data transformation into specific performance parameters for a task workload and information flow network model being created.

A Priori Analyses

Analyses were performed to determine differences in recordings among the three axes of movement (longitudinal, transverse, and vertical) and between the two test participant seats (measured using absorbed power and exposure limit recordings). No significant differences were uncovered between curbside and roadside seating when longitudinal, transverse, and vertical axes movement velocities were individually compared, allowing these data to be collapsed. It was anticipated that differences in movement between test participant seating would not be an issue, since operating procedures for the test track mandate that all vehicles traverse the course in a clockwise direction before noon each day and reverse this direction during the second half of each day (causing seat position to be counterbalanced). However, significant magnitude differences were found among the directions of movement (see Table 3). As expected, the vertical axis (displayed in Figure 7 and profiled in Figures 8 and 9) was found to produce the most pronounced magnitude of vibration in all conditions. Thus, as is normally done in studies of the effects of vibration, the vertical axis (the axis of greatest movement) became the direction of interest and used for velocity measures.

To assay vibration encountered, calculation of PSD was adopted. The average (mean square) acceleration value is equal to the total area under the PSD curve. The PSD describes the general frequency content of the random vibration environment in terms of the spectral density of its mean square value.

Table 3

Statistically Significant Differences in Axes of Vibratory Movement

	DF	Sum of squares	Mean square	F-value	P-value
Longitude					
Speed	2	43699.090	21849.545	11339.802	<.0001
Residual	93	179.193	1.927		
Transverse					
Speed	2	39196.507	19598.254	4248.065	<.0001
Residual	93	429.051	4.613		
Vertical					
Speed	2	24951.628	12475.814	1213.682	<.0001
Residual	93	955.976	10.279		

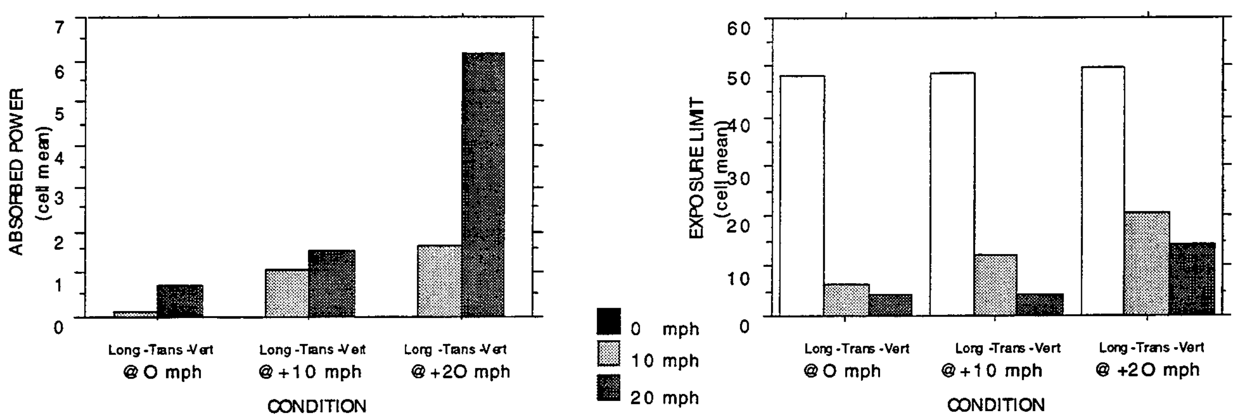


Figure 7. Three axes of movement magnitude, as measured by absorbed power recording and the exposure limit method.

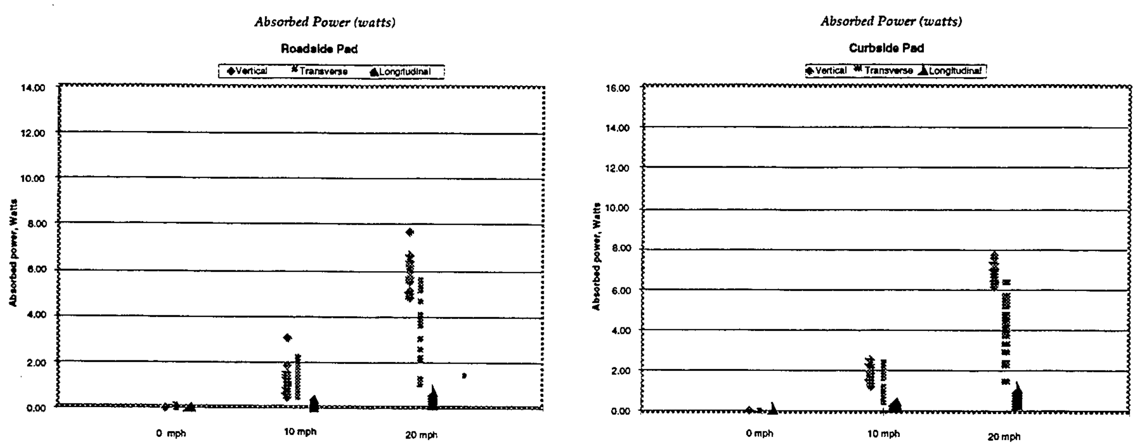


Figure 8. Profile of three-directional absorbed power vibration measurements, taken from roadside and curbside seats, incurred at conditions of 0 mph and approximately 10 and 20 mph.

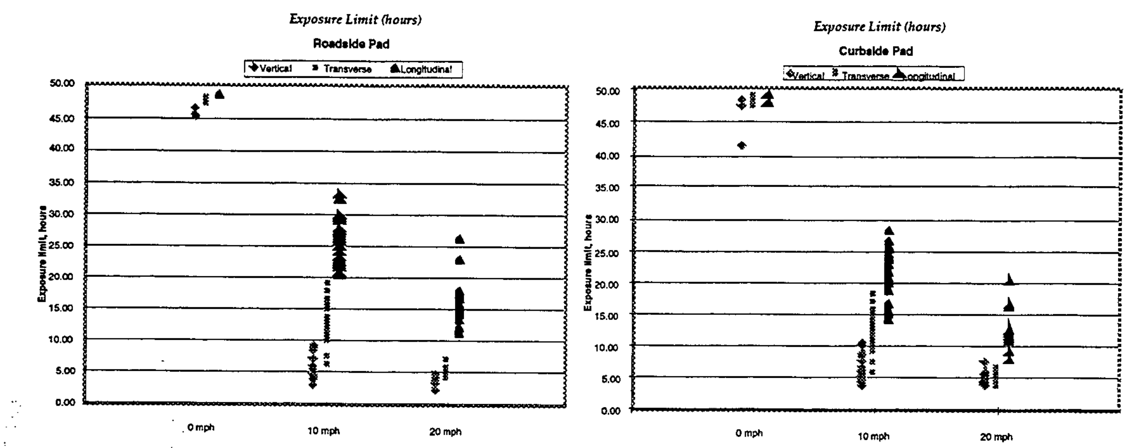


Figure 9. Profile of three-directional exposure limit vibration measurements, taken from roadside and curbside seats, incurred at conditions of 0 mph. and approximately 10 and 20 mph.

Since an actual tracked vehicle traversing off-road terrain provided the vibration environment for this test, this environment is typically described as narrowband random or random vibration. When the data are examined in the frequency domain, they appear as speed-related harmonics that are superimposed on a relatively flat random floor. In the test, the acceleration data were examined in the frequency domain, by creating PSD plots for the 0.3-Hz to 100-Hz region. This range was chosen based on the ISO-2631 (ISO-6311-1974) and absorbed power ride quality analysis methods. These methods provide single number descriptors of the vibration environment based on the PSD. In the case of the ISO method, a limit (in hours) is selected, based on the energy at one particular frequency in the 0.3-Hz to 100-Hz region. The absorbed power method weighs the entire region (0.3 to 100 Hz) and then integrates this to determine the amount of power absorbed at the measurement location.

Vibration measures collected during this exercise (see Figure 10) peaked at the +20-mph condition (amplitude of 0.88 *g* by a frequency of 3 cps), followed by a lesser degree during the +10-mph condition (amplitude of 0.65 *g* by a frequency of 4 cps), and was minimal during instances of the 0-mph condition (amplitude of 0.03 *g* by a frequency of 12.5 cps). Vibration of 0.20 *rms g* is considered high if a human is exposed to it for an extended period of time.

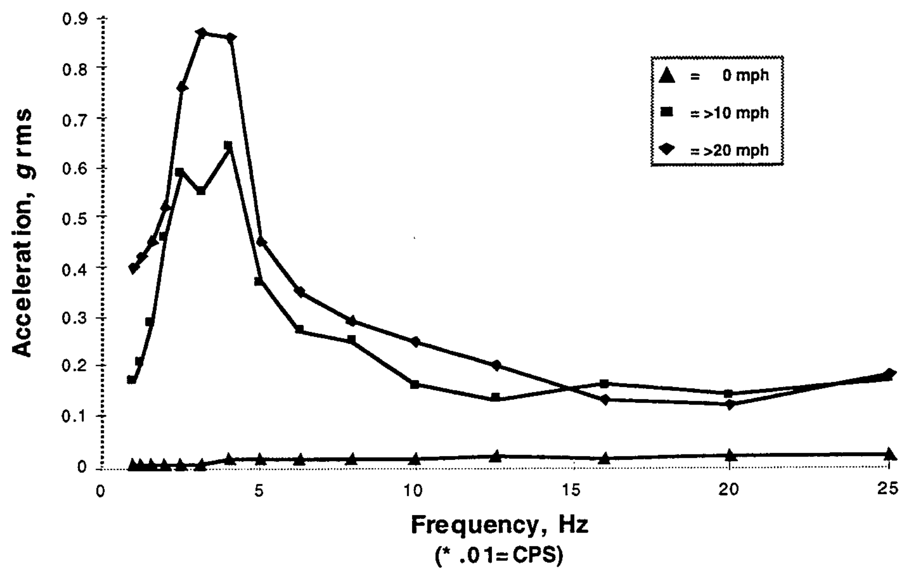


Figure 10. Accrued acceleration by frequency measures.

Main Effects Analyses

Observation of overall results reveals a performance decrement as an effect of environment (see Figure 11).

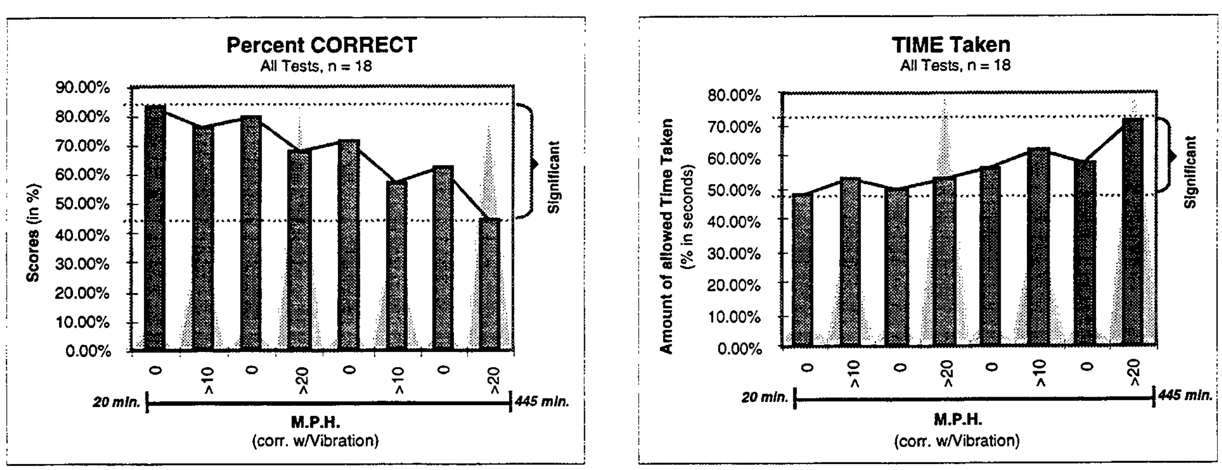


Figure 11. General observation of results for two dependent measures.

The first question asked was if tests administered (and as such, the concepts assessed by these) significantly differed. This was found true (see Table 4). Fortunately, differences between subjects were not significant (for the present analyses, only p values above the .01 level are considered significant).

Table 4

Statistically Significant Differences of Tests Administered

	DF	Sum of squares	Mean square	F-value	P-value
ANOVA table for percent correct trials					
Test	5	13.746	2.749	75.544	<.0001
Residual	858	31.224	.036		
Model II estimate of between component variance: .019					
ANOVA table for percent time					
Sub	17	1.228	.072	1.669	.0433
Residual	846	36.634	.043		

The next question posed was if levels of vibration (noted here as *conditions*) significantly affected test performance, which was also found true (see Figure 12).

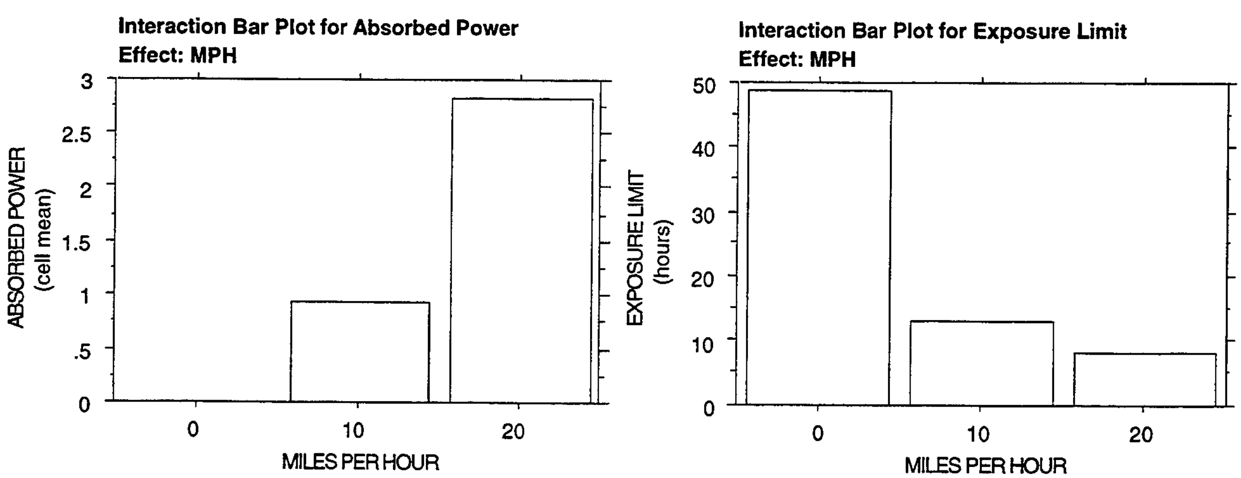


Figure 12. Graphed effects of vibratory condition, in absorbed power and exposure limit criteria.

The resulting question was if performance in *tests* was significantly affected by the *sessions* administered at (one through eight administrations of the test batteries). This was found true for both dependent variables, where for percent correct $F(5, 102) = 40.507, p < 0.001$, and for time taken to complete tests $F(5, 102) = 130.818, p < 0.001$ (see Tables 5 and 6). Test performance decreased and time to complete tests increased as the day progressed.

Table 5

Statistically Significant Differences in Test Performance as a Function of Administration Session

ANOVA table for percent CORRECT, effect Test

	DF	Sum of squares	Mean square	F-value	P-value
Test	5	13.746	2.749	40.507	<.0001
Subject (group)	102	6.923	.068		
Category for percent correct, sessions	7	12.437	1.777	150.031	<.0001
Category for percent correct, sessions*test	35	3.409	.097	8.225	<.0001
Category for percent correct, sessions*subject (group)	714	8.456	.012		

Table 6

Statistically Significant Differences in Time Taken to Complete Tests as a Function of Session When Administered

ANOVA table for TIME taken, effect Test

	DF	Sum of squares	Mean square	F-value	P-value
Test	5	23.464	4.693	130.818	<.0001
Subject (group)	102	3.659	.036		
Category for percent time, sessions	7	4.396	.628	107.242	<.0001
Category for percent time, sessions*test	35	2.162	.062	10.551	<.0001
Category for percent time, sessions*subject (group)	714	4.181	.006		

A consequence of this was to determine when and then where these effects took place. Generally, all tests degraded over time and appeared to do so by Session Number 4 of test administration (see Figure 13).

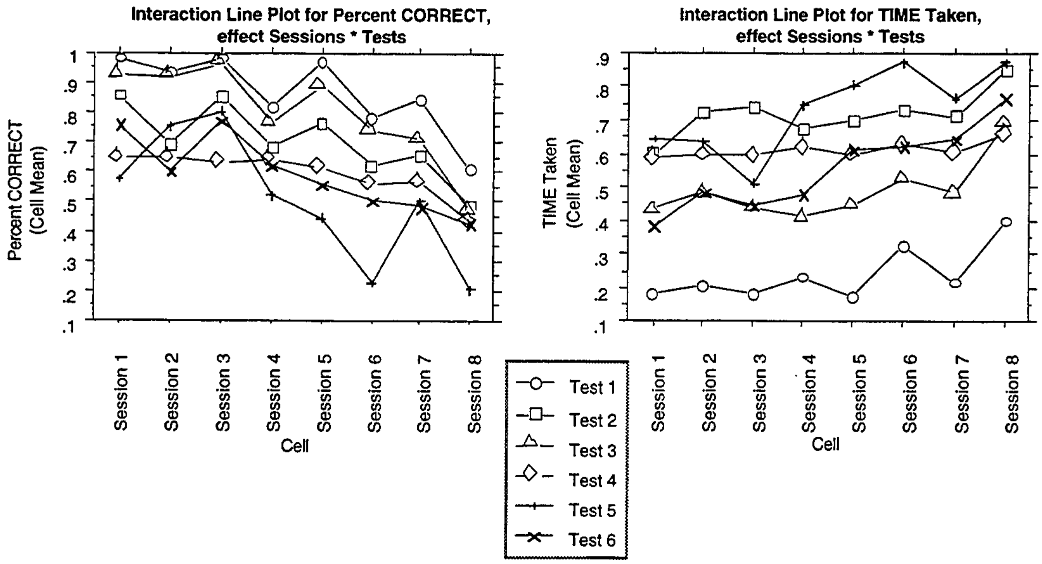


Figure 13. Plots of performance recorded and time taken to complete tests by session.

Statistically significant results (from baseline, or first test administration) were obtained for combined test scores and times taken to complete tests as sessions progressed (see Table 7). Statistically significant differences (from initial session) generally began to appear at Session Number 4 (see Table 8). Such results usually reappeared at Trial Number 6 and continued through Trials 7 and 8 until the end of the testing period. These results appear logical, as Trial Number 4 was test participants' first exposure to the highest vibratory period of the test. During Trial Number 5, participants were exposed a third time to the minimum vibration condition given during the day. At Trial Number 6, participants were exposed to moderate vibration for a second time that day. At Trial Number 7, participants were again exposed to the minimum vibration but for their fourth time during the day; thus, the data began to show cumulative effects of the environment. At Trial Number 8, participants were exposed to the greatest amount of vibration for their second time during the day, and performance always decreased.

Collectively, comparing among tests by means (for percent correct), the lowest test mean recorded appears at Test Number 5 (Route Planning), followed by increases at Test Numbers 4 (Sternberg's Memory Search Task) and 6 (Missing Items) with means almost equal. These were followed by a higher mean for Test Number 2 (Mathematical Processing Task), then even higher for Test Number 3 (Grammatical Reasoning Task), and finally Test Number 1 (Continuous Recall Task) recorded the highest mean percent correct scores of all (see Figure 14).

Table 7

Statistical Significance for Found for the Effect of Test Administration Session

ANOVA table for percent CORRECT, all sessions

	DF	Sum of squares	Mean square	F-value	P-value
Session	7	12.437	1.777	46.749	<.0001
Residual	856	32.533	.038		

Model II estimate of between component variance: .016

Table 8

Sessions Results as Compared With Baseline

Scheffé for percent CORRECT, Effect: All SESSIONs, Significance level: 5%

Test	Mean difference	Critical difference	P-value	
1,2	.033	.100	.9819	
1,3	-.043	.100	.9136	
1,4	.116	.100	.0088	S
1,5	.082	.100	.2096	
1,6	.220	.100	<.0001	S
1,7	.163	.100	<.0001	S
1,8	.351	.100	<.0001	S

Collectively, comparing among tests means (for time taken of the amount allowed), it took participants the longest to complete Test Number 5 (Route Planning), followed almost equally in time taken by Test Number 2 (Mathematical Processing Task). Test Number 4 (Sternberg's Memory Search Task) took third longest to complete, followed by Test Number 6 (Missing Items), Test Number 3 (Grammatical Reasoning Task), and finally Test Number 1 (Continuous Recall Task) (see Figure 15).

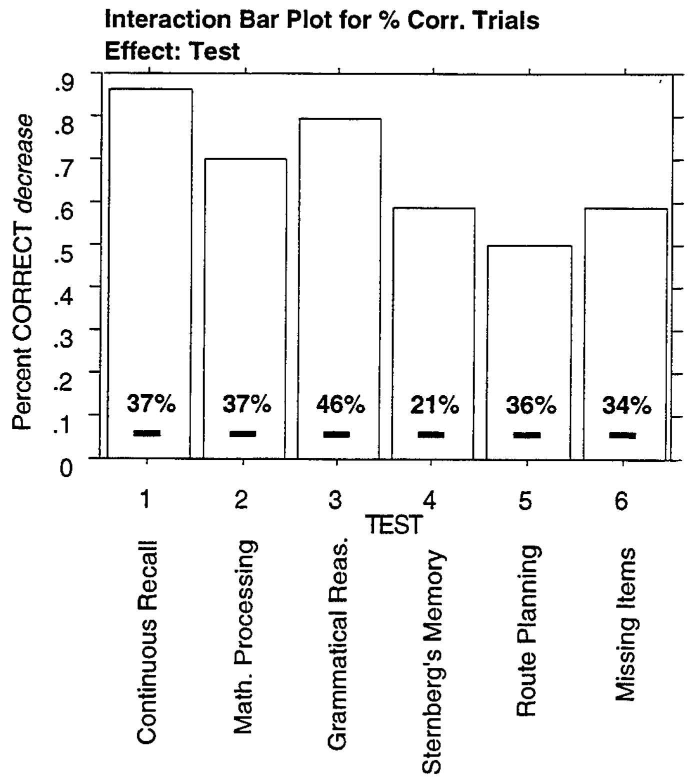


Figure 14. Graph of overall test results for the percent correct dependent variable.

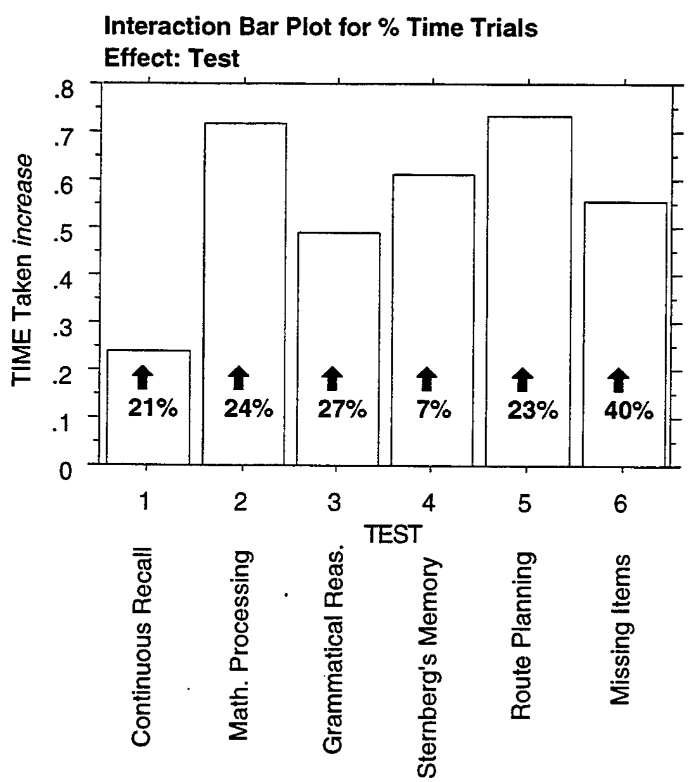


Figure 15. Graph of overall test results for the time taken dependent variable.

However, although differences found between test means are interesting in that they speak to the degree of difficulty present in testing a given concept, of greater importance is the amount of performance decrement found *within* concepts. In Figures 14 and 15, notice the percentage number embedded within bars for each test, displaying the total range of performance deviation for that concept. Apparently, the greatest regressive degree of test difficulty experienced by participants when measuring percent correct, given the environment, was for the concept time sharing (test 3). This was followed closely by the concepts selective attention (test 1) and inductive reasoning (test 2); these were followed closely by the concept spatial orientation (test 5), then the concept speed of closure (test 6), and least deviation was seen for the concept memorization (test 4). Measuring time taken to complete, greatest deviancy (degree of difficulty) was found for the concept speed of closure (test 6), followed by the concept time sharing (test 3), then by the concepts inductive reasoning (test 2) and spatial orientation (test 5), then the concept selective attention (test 1), and finally least affected by the environment appears to be the concept memorization (test 4).

For tests that were observed individually (and as such, the cognitive process each measured), the results are recorded in Figure 16, with graphs of percent correct along the left column and time taken to complete tests along the right. Each test, given repeatedly over a period of eight sessions, was compared to its baseline of Session Number 1. Recorded were significant differences from baseline, determining performance decrement. As a reference for when (which minutes) during the day sessions took place, refer to Figure 16. Note that cognitive battery administration periods were approximately 40 minutes long, stress assessment approximately 15 minutes, and before testing began, 90 minutes were usually spent administering first stress battery, an amylase assay, pre-test questionnaires, volunteer consent affidavits, taking time for calibrating all electrical and other apparatus for the day, and a vibration acclimation ride. A typical test day began at 0730 hours and ended approximately 515 minutes later (almost 9 hours total).

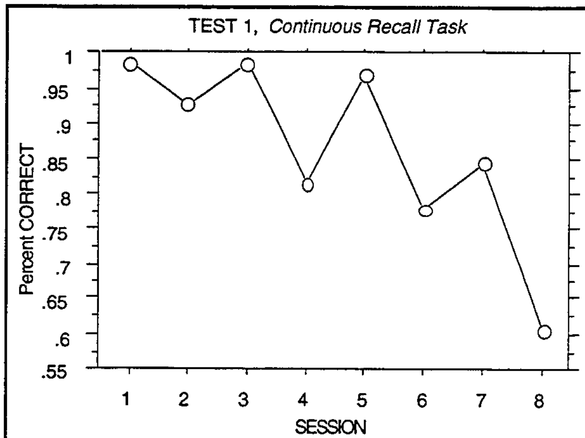
	session #1		session #2		session #3		session #4		session #5		session #6		session #7		session #8	
(90)	40	15	40	15	40	15	40	15	40	15	40	15	40	15	40	15
	55		**110**		**165**		**220**		**275**		**330**		**385**		**440**	

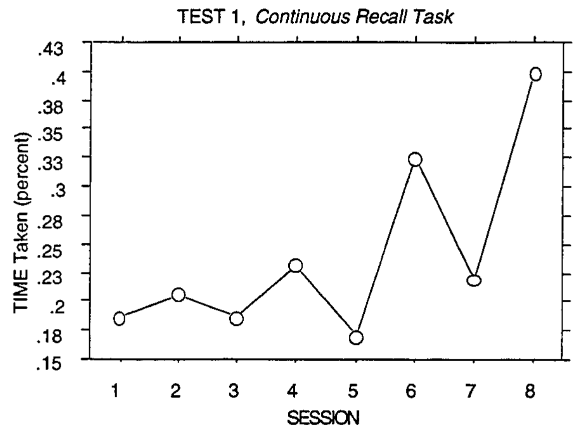
MINUTES (cumulative)

Figure 16. Experimental *sessions* displayed with corresponding time of day.

Observed in increments of sessions, the combined effects of increased vibration and time in the vehicle significantly affected performance (measured as percent correct answers on tests). Test Number 1 (measuring the concept selective attention [see Figure 17]) displayed the performance hypothesized, with highest baseline scores (98% correct), followed by a fall in performance over sessions (ending at 61%, a 37% fall from baseline). A slight effect of vibration can be seen at Session Number 2 (the first 10-mph vibration exposure), a significant fall at Session 4 (the first 20-mph vibration exposure), and finally a dramatic performance fall-off is seen from Session 6 (the second 10-mph vibration exposure) and continues through until the end of the day. Test Number 3 (measuring the concept time sharing, see Figure 19) followed the pattern of Test Number 1 but with slightly lower performances recorded at each session (beginning at a baseline performance of 92 percent and falling to 46% performance by day's end, a 46% decrease). A significant decrement in performance began at Session Number 6 (the second 10-mph vibration exposure) and continued through until the end of the day. Test Number 2 (measuring the concept inductive reasoning [see Figure 18]) mimicked Tests 1 and 3, recording performances lower than both at each session and ending with performance similar to Test Number 3 (performance degradation of 37%, from a baseline measure of 87% down to 50% at day's end). Significant performance degradation was seen at all sessions where participants were exposed to vibration. Test Number 6 (measuring the concept speed of closure [see Figure 22]) resulted in performance scores less than the preceding three tests; however, performance began to decline significantly at Session Number 5 (the third 0-mph vibration exposure) and steadily significantly declined from this. Scores fell from a baseline average of 76% to 42% by the end of the day (a 34% decrease in performance). Test Number 4 (measuring the cognitive concept of memorization [see Figure 20]) remained most consistent throughout the day. Beginning with a baseline average performance of 64%, this fell to 43% by the end of the day (a 21% decrease in performance). Performance decrement became significant at Session Number 6 (the second 10-mph vibration exposure), then fell more dramatically at Session Number 8 (the second 20-mph vibration exposure). Test Number 5 (measuring the concept spatial orientation [see Figure 21]) produced the most erratic results. Beginning at a baseline performance average of 57%, performance rose at Session 3 (the second 0-mph vibration exposure). At Session Number 6 (the second 10-mph vibration exposure), performance fell significantly to the lowest of all tests, climbed at Session 7 (the third 0-mph vibration exposure), and fell again to end at 21% (a 36% decease in performance).

Again, the combined effects of increased vibration and time in the vehicle significantly affected the time it took participants to complete tests (measured as percent taken of the time allowed). Test Number 1 (measuring the concept selective attention [see Figure 17]) displayed the lowest and most stable test time completion record, until Session Number 6 (second 10-mph vibration exposure), where time increased significantly. Time to complete then decreased at Session Number 7 (the third 0-mph vibration exposure) but jumped significantly to highest for this test at Session Number 8 (the second 20-mph vibration exposure). Although resulting in lowest times for test completion of all test administered, time to complete this test rose from a baseline of 19% to 40% by the end of the day (an increase of 21%). Test Number 6 (measuring the concept speed of closure [see Figure 22]) began with the second lowest baseline average time to complete of 37%, rising to 77% by the end of the day. This test remained somewhat stable until Session Number 5 (the third 0-mph vibration exposure) when a rise in time became noticeable and the increase continued. Test Number 6 performance ended with the third longest average times to complete all tests (an increase of 40% over the day). Test Number 3 (measuring the concept time sharing [see Figure 19]) began with a baseline average time to complete slightly higher than Test Number 6 (43%), ending with a final average time to complete slightly lower than Test Number 6 (70%). Although remaining stable throughout most of the day, average time to complete this test began rising at Session Number 5 (the third 0-mph vibration exposure) and jumped significantly to worst at Session Number 8 (the second 20-mph vibration exposure), a 27% increase in times to complete this test over the day. Test Number 4 (measuring the cognitive concept of memorization [see Figure 20]) remained most consistent throughout the day of all tests. Beginning with a baseline time to complete test of 59%, time rose only to 66% by the day's end (a 7% increase). Significant increases in test times were seen at the final three vibration exposure sessions. Test Number 2 (measuring the concept inductive reasoning [see Figure 18]) began with a baseline time to complete similar to test Number 4 (60%), showed an increase at Sessions Number 2 (the first 10-mph vibration exposure) and 3 (second 0-mph vibration condition) and then significantly and steadily increased, jumping to 84% of allowed time taken to complete test by Session Number 8 (second 20-mph vibration exposure and the end of the day). Total increase in time to complete this test over the day was 24%. Test Number 5 (measuring the concept spatial orientation [see Figure 21]) began with the highest baseline time to complete (65%) and ended with the highest time to complete (88%). Average times to complete this test were most sporadic of all tests. Times decreased at Session Number 3 significantly (the second 0-mph vibration exposure), then markedly (significantly) increased by Sessions Number 5 (the third 0-mph vibration exposure) and 6 (the second 10-mph vibration exposure). A decrease in time to complete resulted at Session Number 7 (the third 0-mph vibration exposure), but completion times again rose to highest by Session Number 8 (the second 20-mph vibration exposure and the end of the day). Total increase in average time to complete for this test over the day was 23%. As for the dependent variable percent "correct," this test once again resulted in the most erratic performance of all.

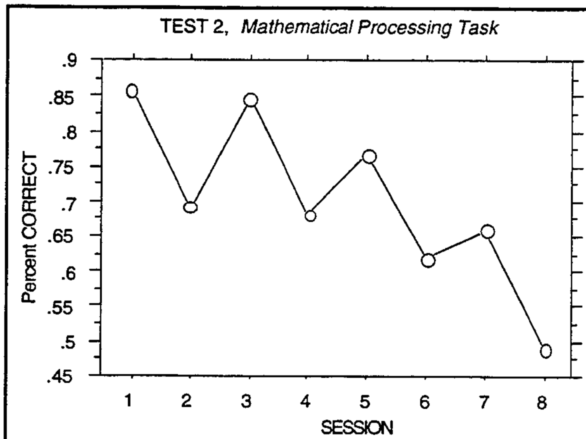


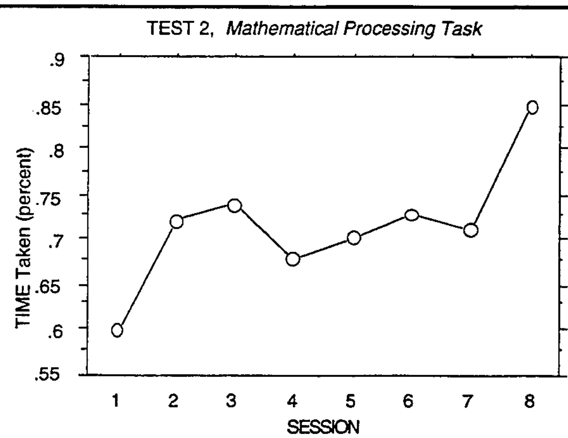


	Mean Diff.	Crit. Diff	P-Value	
1, 2	.054	.123	.1609	
1, 3	0.000	.123	•	
1, 4	.167	.123	<.0001	S
1, 5	.016	.123	.6877	
1, 6	.205	.123	<.0001	S
1, 7	.141	.123	.0004	S
1, 8	.378	.123	<.0001	S

	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.020	.085	.4553	
1, 3	2.776E-17	.085	>.9999	
1, 4	-.047	.085	.0793	
1, 5	.014	.085	.6040	
1, 6	-.141	.085	<.0001	S
1, 7	-.034	.085	.2067	
1, 8	-.216	.085	<.0001	S

Figure 17. Plots of percent correct and time taken to complete by session, for the 'Continuous Recall' task measuring *selective attention.*

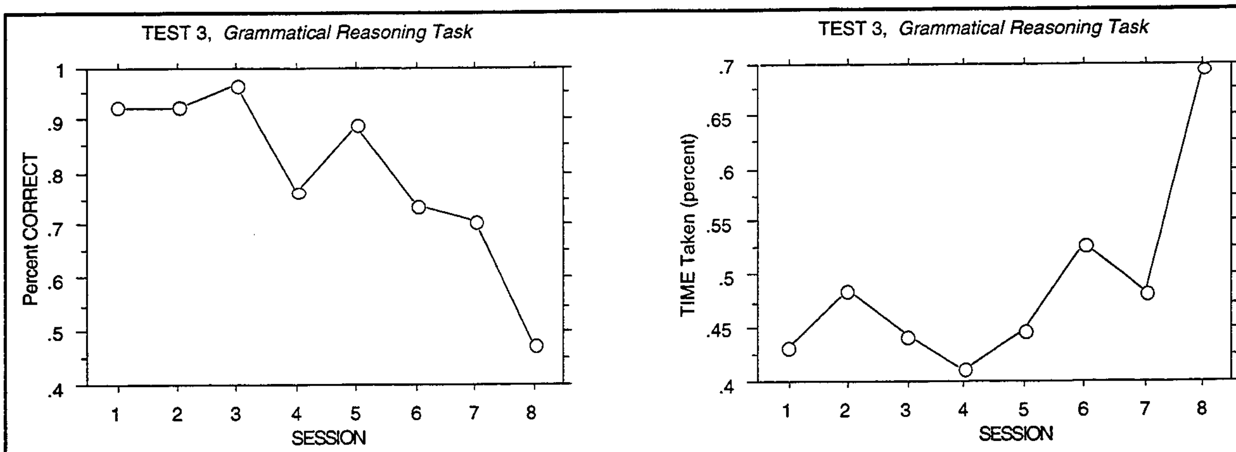




	Mean Diff.	Crit. Diff	P-Value	
1, 2	.166	.130	<.0001	S
1, 3	.008	.130	.8490	
1, 4	.174	.130	<.0001	S
1, 5	.089	.130	.0300	
1, 6	.237	.130	<.0001	S
1, 7	.198	.130	<.0001	S
1, 8	.367	.130	<.0001	S

	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.122	.100	.0002	S
1, 3	-.142	.100	<.0001	S
1, 4	-.082	.100	.0102	
1, 5	-.102	.100	.0015	S
1, 6	-.130	.100	<.0001	S
1, 7	-.111	.100	.0005	S
1, 8	-.251	.100	<.0001	S

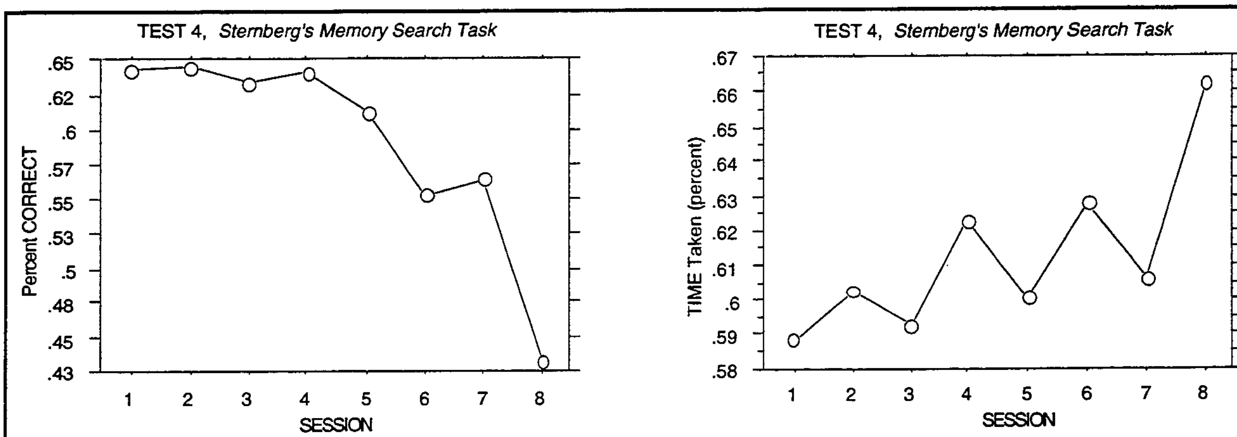
Figure 18. Plots of percent correct and time taken to complete by session, for the 'Mathematical Processing' task measuring *inductive reasoning.*



	Mean Diff.	Crit. Diff	P-Value	
1, 2	.001	.166	.9915	
1, 3	-.038	.166	.4623	
1, 4	.160	.166	.0025	
1, 5	.033	.166	.5296	
1, 6	.187	.166	.0004	S
1, 7	.217	.166	<.0001	S
1, 8	.451	.166	<.0001	S

	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.055	.108	.1070	
1, 3	-.010	.108	.7684	
1, 4	.021	.108	.5453	
1, 5	-.016	.108	.6471	
1, 6	-.097	.108	.0050	
1, 7	-.052	.108	.1258	
1, 8	-.262	.108	<.0001	S

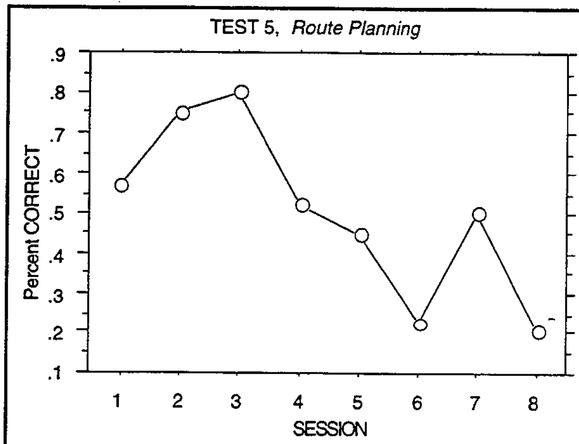
Figure 19. Plots of percent correct and time taken to complete by session, for the 'Grammatical Reasoning' task measuring *time sharing*.



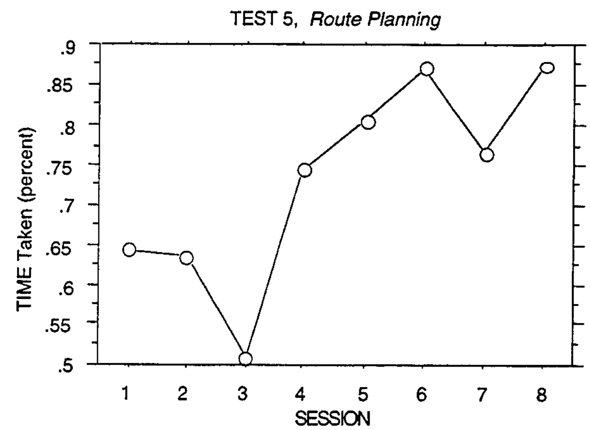
	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.002	.063	.9334	
1, 3	.009	.063	.6361	
1, 4	.002	.063	.9334	
1, 5	.029	.063	.1492	
1, 6	.088	.063	<.0001	S
1, 7	.078	.063	.0001	S
1, 8	.209	.063	<.0001	S

	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.014	.031	.1440	
1, 3	-.004	.031	.6519	
1, 4	-.034	.031	.0006	S
1, 5	-.012	.031	.2373	
1, 6	-.040	.031	<.0001	S
1, 7	-.018	.031	.0727	
1, 8	-.073	.031	<.0001	S

Figure 20. Plots of percent correct and time taken to complete by session, for the 'Sternbergs Memory Search' task measuring *memorization*.

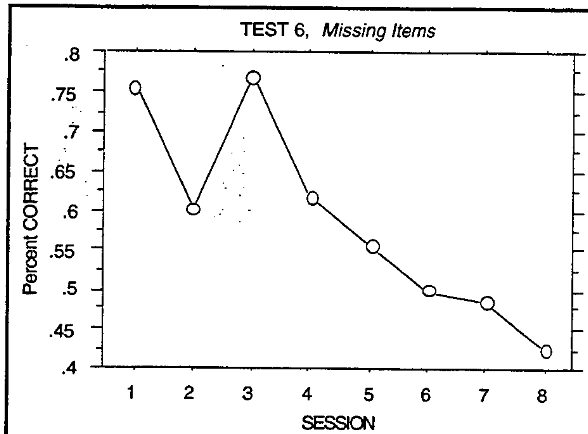


	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.177	.212	.0086	
1, 3	-.224	.212	.0010	S
1, 4	.055	.212	.4096	
1, 5	.129	.212	.0536	
1, 6	.349	.212	<.0001	S
1, 7	.073	.212	.2720	
1, 8	.369	.212	<.0001	S

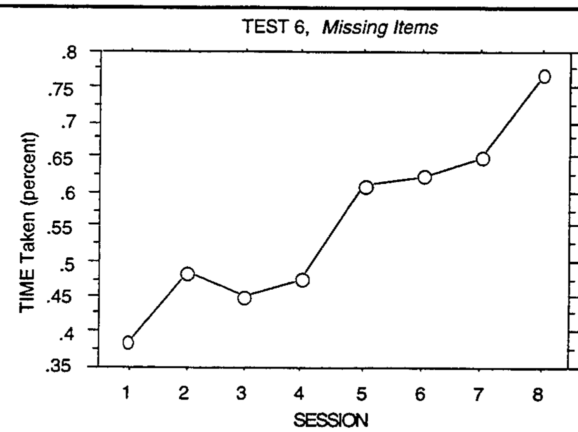


	Mean Diff.	Crit. Diff	P-Value	
1, 2	.008	.126	.8328	
1, 3	.135	.126	.0008	S
1, 4	-.099	.126	.0132	
1, 5	-.160	.126	<.0001	S
1, 6	-.226	.126	<.0001	S
1, 7	-.122	.126	.0024	
1, 8	-.229	.126	<.0001	S

Figure 21. Plots of percent correct and time taken to complete by session, for the 'Route Planning' task measuring *spatial orientation.*



	Mean Diff.	Crit. Diff	P-Value	
1, 2	.154	.138	.0005	S
1, 3	-.015	.138	.7304	
1, 4	.136	.138	.0022	
1, 5	.199	.138	<.0001	S
1, 6	.254	.138	<.0001	S
1, 7	.273	.138	<.0001	S
1,.8	.331	.138	<.0001	S



	Mean Diff.	Crit. Diff	P-Value	
1, 2	-.102	.139	.0209	
1, 3	-.064	.139	.1463	
1, 4	-.093	.139	.0357	
1, 5	-.226	.139	<.0001	S
1, 6	-.238	.139	<.0001	S
1, 7	-.264	.139	<.0001	S
1, 8	-.382	.139	<.0001	S

Figure 22. Plots of percent correct and time taken to complete by session, for the 'Missing Items' task measuring *speed of closure.*

Additionally, sessions of movement tended to differ significantly. Both 10- and 20-mph movement sessions differed significantly when the dependent variable percent correct was observed, as did the second 20-mph movement session when observed in time to complete (see Table 9).

Table 9

Comparison of Sessions of Movement

Scheffé for percent correction Effect: Session Significance level: 5%				Scheffé for percent time Effect: Session Significance level: 5%			
Test	Mean difference	Critical difference	P-value	Test	Mean difference	Critical difference	P-value
2,6	.188	.100	<.0001 S	2,6	-.094	.101	.0935
4,8	.235	.100	<.0001 S	4,8	-.180	.101	<.0001 S

Typing Test Analysis

The typing test (Lessenberry, Crawford, Erickson, Beaumont, & Robinson, 1977) given revealed a significant decrement in performance between the time when subjects were required to type while stationary and when they were asked to type while traveling at 20 mph (see Table 10). Measures were made for differences between the number of words completed and for errors made. As expected and may be seen from the sample given in Figure 23, it was difficult for test participants to type while moving.

Table 10

Statistically Significant Typing Performance, as a Function of Vibration

Paired t-test Hypothesized difference = 0	Mean difference	DF	t-value	P-value
Words @ 0 mph, Words @ 20 mph	18.167	17	8.916	<.0001
Error @ 0 mph, Error @ 20 mph	-8.667	17	-7.415	<.0001

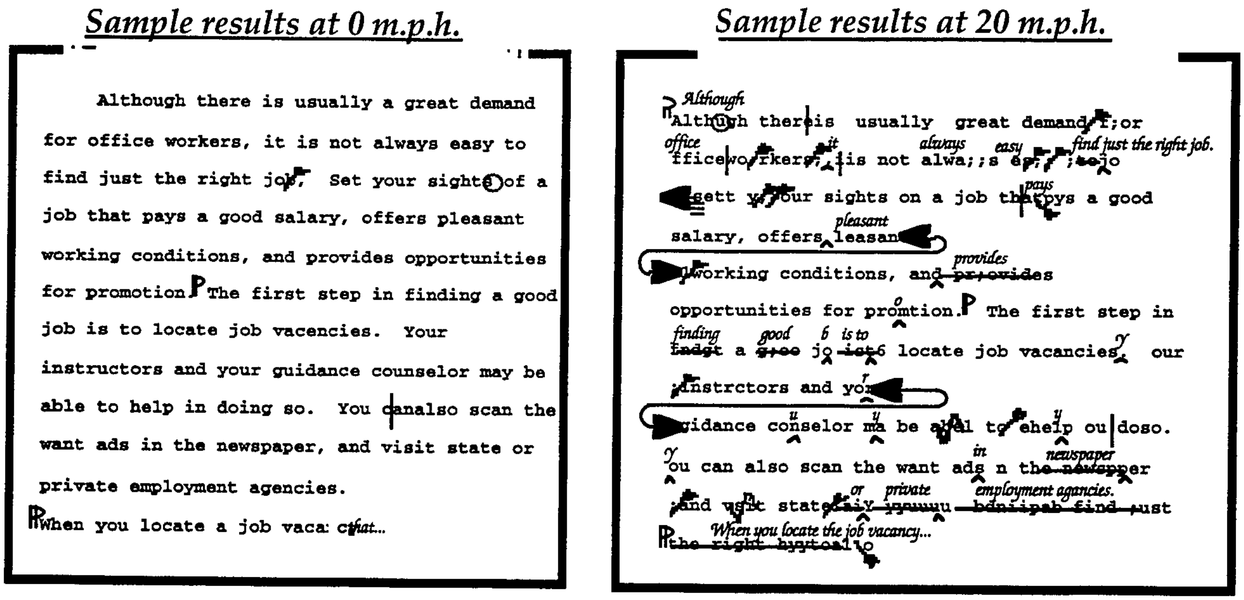


Figure 23. Sample typing test results, taken at conditions of 0 mph (left) and approximately 20 mph (right).

Stress Effects Analyses

Psychological data from this experiment were compared with data from an independent control group (INDCNTRL) of men investigated during normal work days when they were experiencing no unusual stress. The INDCNTRL represents a relatively low stress level to a condition of no stress.

A multivariate analysis of variance (MANOVA) was conducted to compare baseline and pre-test data with the pre-stress data obtained in the INDCNTRL. The participants of this study did not report stress levels significantly different from those of the INDCNTRL. The psychological measures of anxiety used in this study (MAACL-R anxiety and subjective stress scale) typically relate to the level of uncertainty perceived by the individual. Test participants in the study reported relatively low levels of anxiety or uncertainty. This result may be because the participants were well informed of their duties or that they were confident in their abilities to perform well.

A MANOVA was conducted to compare stress measures (MAACL-R) across sessions with the INDCNTRL. Although there was an effect for anxiety (during administration Session Number 4 only) where $F(1,33) = 4.944$, $p = .033$, overall there were no significant differences for other sessions. A MANOVA was conducted to compare sessions across test day. Although there was an overall main effect for Sessions (Wilks' λ =.000; $F(9,1) = 375.755$; $p = .040$) there was no significant interaction of session by MAACL-R per Wilks' $\lambda = .597$; $F(4,6) = 1.014$; $p = .469$.

A MANOVA was conducted to compare subjective stress measures across sessions with the INDCNTRL. Participants reported levels of subjective stress relative to those of the INDCNTRL. There were no significant differences as $F(9,63) = 1.679$, $p = 0.113$. A MANOVA was conducted to compare levels of sleepiness and fatigue scores across sessions. Results showed the participants not significantly sleepy as $F(9,72) = 1.321$, $p = 0.241$ or fatigued enough to affect stress levels, as $F(9,81) = 1.723$, $p = 0.097$.

Finally, a MANOVA was conducted to compare levels of amylase across sessions. There were no significant differences between sessions. The MANOVA concluded that there was no variance of the dependent variable.

Regression

After cognitive test correlation was identified with operational factors, regression was used to develop the functional relationship. However, to put results found into perspective, correlations were first observed. It was logical to find the independent variable *condition* correlated highly with other independents *absorbed power* (.841) *exposure limit* (-.892) and *noise* (.985) and correlated with *session* (.329) (see Tables 11 and 12). Absorbed power measures and the exposure limit criteria should directly reflect the vibratory condition given test participants. Noise increased as vehicle speed increased which, in turn, increased per vibratory condition, and although sessions were randomized into three degrees of vibration, correlation shown here would account for varying degrees of this. Also, for both dependent measures, the independents *absorbed power* and *exposure limit* were highly correlated (-.647), which supports statements made throughout literature that these measures are somewhat interchangeable. The high correlation found for the independent *endurance* with both dependent measures percent <u>correct</u> (-.622) and <u>time</u> (.617) taken to complete tests emphasizes its predictive strength. The same may be said for the effect on percent <u>correct</u> for the predictors *session* (-.462) and *absorbed power* (-.389) though to a lesser degree and for the predictor *session* (.302) on the dependent <u>time</u> to complete. Partial correlations of less than 0.3 were considered poor.

Table 11

Correlation Matrix for Percent CORRECT Versus Seven Anticipated Independents

Correlation matrix	Endurance	Absorbed power	Exposure limit	Session	Noise	Subject	Condition	Percent correct
Endurance	1.000	.197	-.024	.220	.082	0.000	.065	-.622
Absorbed power	.197	1.000	-.647	.369	.821	-.003	.841	-.389
Exposure limit	-.024	-.647	1.000	-.195	-.904	-.001	-.892	.262
Session	.220	.369	-.195	1.000	.348	0.000	.329	-.462
Noise	.082	.821	-.904	.348	1.000	8.317E-16	.985	-.334
Subject	0.000	-.003	-.001	0.000	8.317E-16	1.000	0.000	.031
Condition	.065	.841	-.892	.329	.985	0.000	1.000	-.327
Percent correct	-.622	-.389	.262	-.462	-.334	.031	-.327	1.000

Table 12

Correlation Matrix for Percent TIME Taken Versus Seven Anticipated Independents

Correlation matrix	Endurance	Absorbed power	Exposure limit	Session	Noise	Subject	Condition	Percent correct
Endurance	1.000	.197	-.024	.220	.082	0.000	.065	.617
Absorbed power	.197	1.000	-.647	.369	.821	-.003	.841	.270
Exposure limit	-.024	-.647	1.000	-.195	-.904	-.001	-.892	-.157
Session	.220	.369	-.195	1.000	.348	0.000	.329	.302
Noise	.082	.821	-.904	.348	1.000	8.317E-16	.985	.196
Subject	0.000	-.003	-.001	0.000	8.317E-16	1.000	0.000	-.037
Condition	.065	.841	-.892	.329	.985	0.000	1.000	.190
Percent time	.617	.270	-.157	.302	.196	-.037	.190	1.000

Given this, and considering predictors that must be observed in an environment such as that to which participants were subjected, the five predictors of interest became *endurance*, *session*, *absorbed power*, *exposure limit*, and *noise* (eliminating *subject* since the effect of this variable on performance was not significant, and *condition* since this would be assessed by observation of the variables *session* and *endurance*).

The selected predictors of the two dependent variables (percent correct and time taken to complete tests) were observed collectively for their ability to account for variance in the data and individually for their magnitude of prediction. In combination, the predictor variables *endurance*, *session, absorbed power, exposure limit,* and *noise* returned a multiple *R* value for the dependent variable percent correct of .733 ($p < .0001$) and for the dependent variable time to complete of .649 ($p < .0001$), as is shown in Tables 13 and 14. A significant interception found is attributable to the large incremental ranges between individual predictors.

Table 13

Multiple Regression for Percent CORRECT Versus Five Independents

Regression summary, percent CORRECT versus five independents

Count	864
Number missing	0
R	.733
R squared	.537
Adjusted R squared	.535
rms residual	.156

ANOVA table percent CORRECT versus five independents

	DF	Sum of squares	Mean square	F-value	P-value
Regression	4	24.148	6.037	249.054	<.0001
Residual	859	20.822	.024		
Total	863	44.970			

All predictors were statistically significant in affecting dependent variables. Each test possesses a history of validity in an office environment and would appear to react as expected (successively poorer results gained as time in the environment progressed) by measuring their respective concepts in the field. By reviewing Figures 24 through 28 (five representations of accuracy along the left column and five of time taken along the right), one might appreciate a more graphic depiction of how predictors acted upon the dependents (please note the inclusion of the upper horizontal axis representing "miles per hour" in Figure 27).

Table 14

Multiple Regression for Percent TIME Taken Versus Five Independents

Regression summary, percent TIME taken versus five independents

Count	864
Number missing	0
R	.649
R squared	.422
Adjusted R squared	.420
rms residual	.160

ANOVA table percent TIME taken versus five independents

	DF	Sum of squares	Mean square	F-value	P-value
Regression	4	15.962	5.321	208.946	<.0001
Residual	860	21.900	.025		
Total	863	37.862			

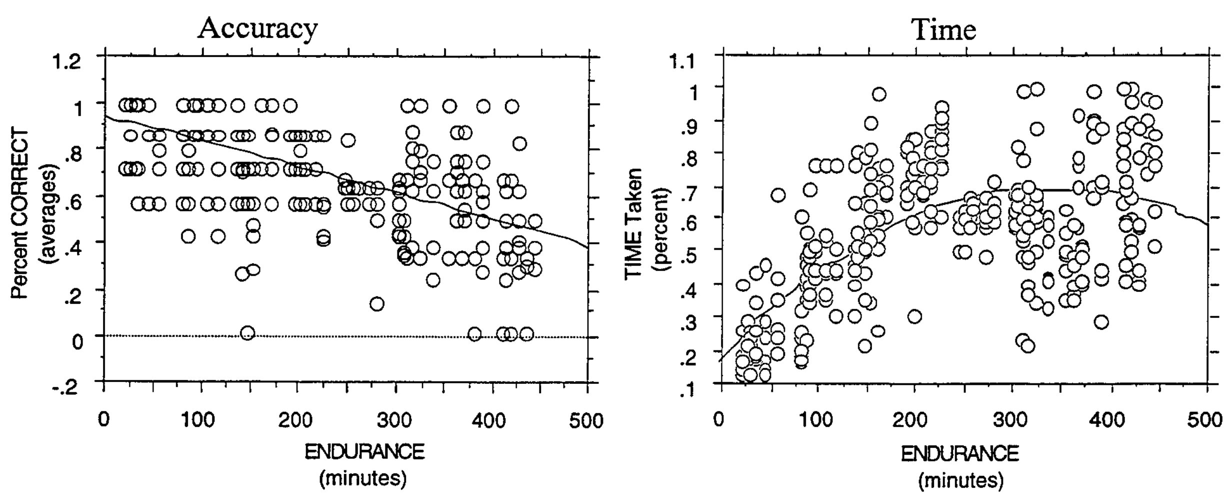


Figure 24. Plots of percent correct and time taken to complete tests by endurance measures.

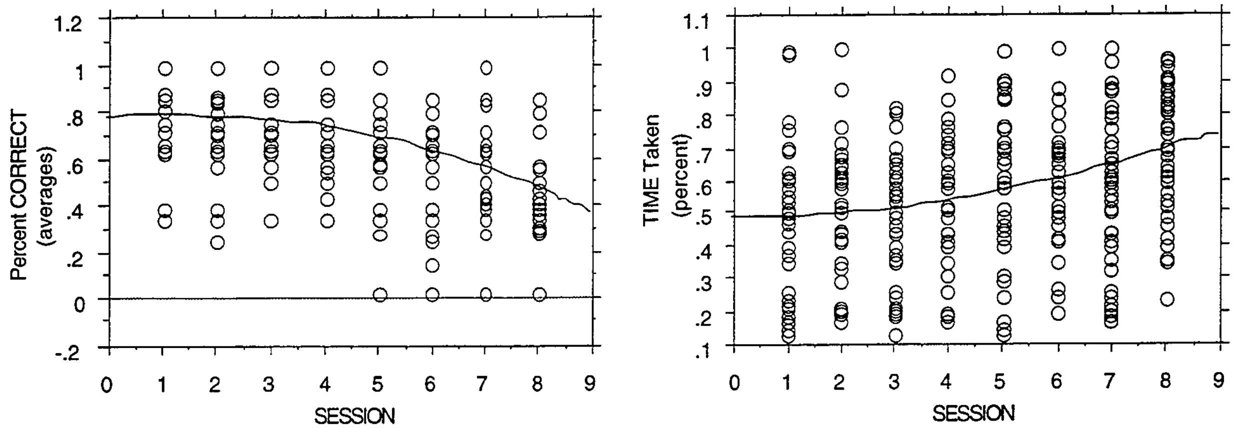


Figure 25. Plots of percent correct and time taken to complete tests by test sessions.

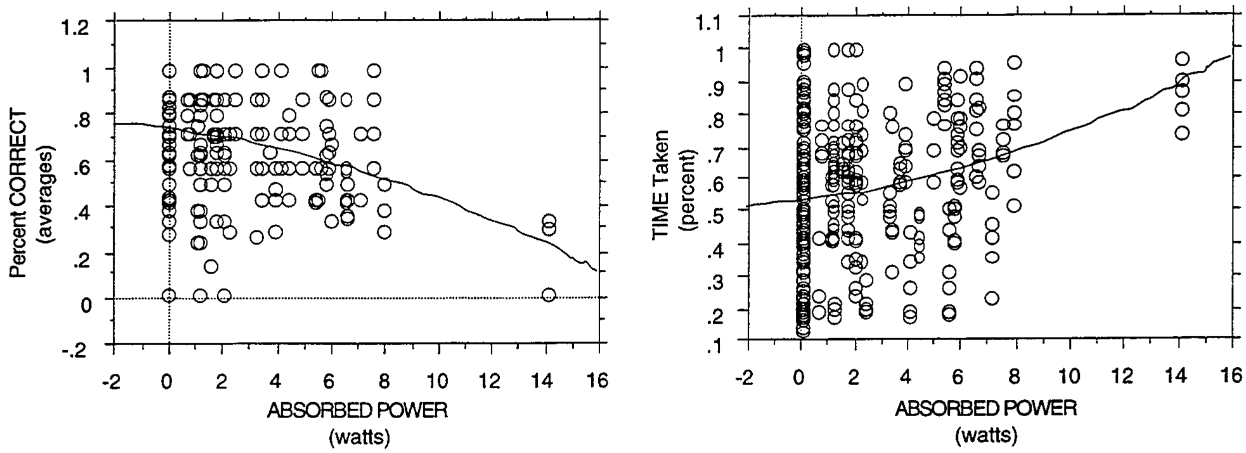


Figure 26. Plots of percent correct and time taken to complete tests by absorbed power recordings.

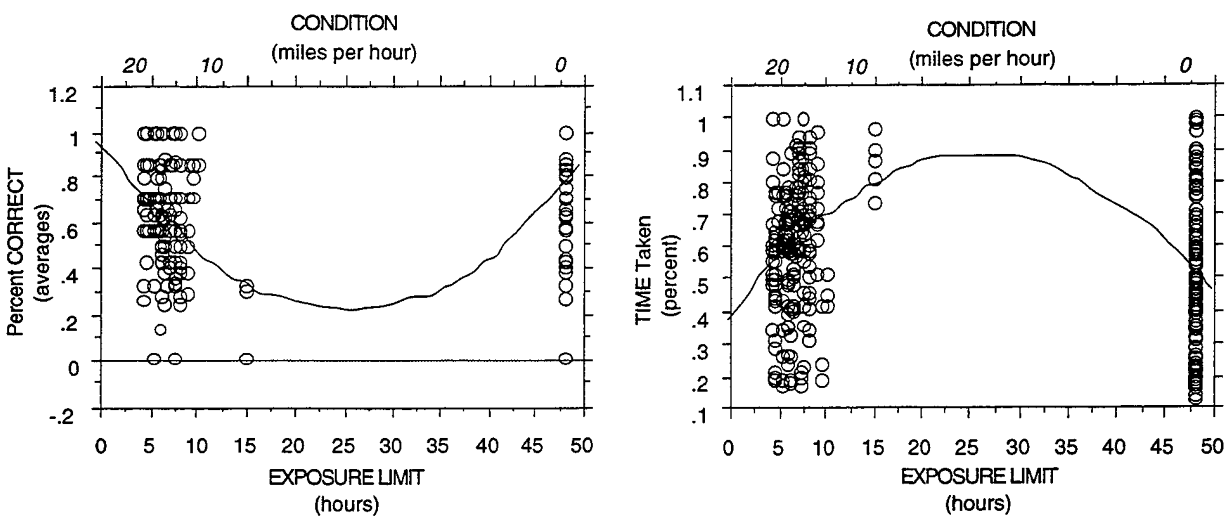


Figure 27. Plots of percent correct and time taken to complete tests by exposure limit criteria.

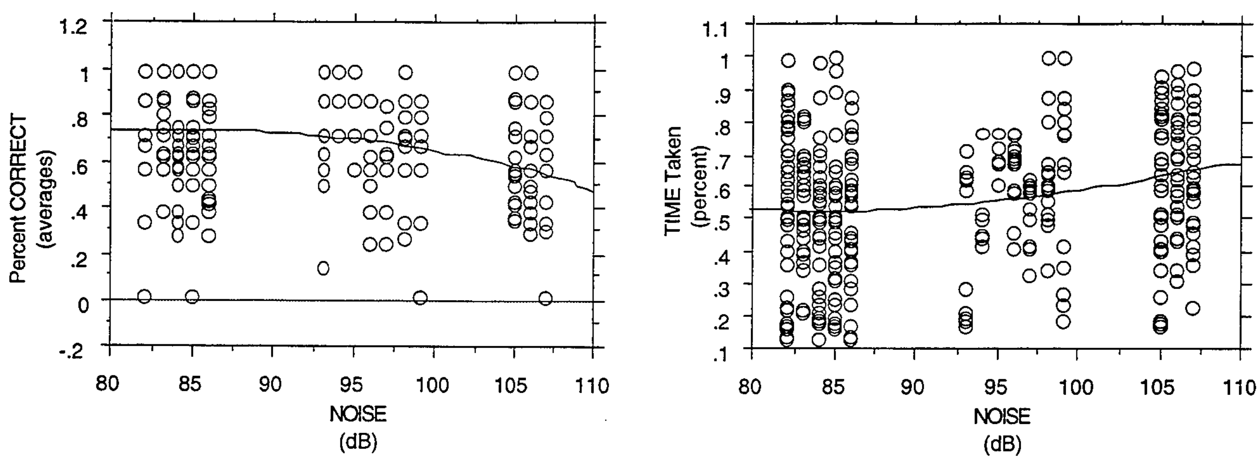


Figure 28. Plots of percent correct and time taken to complete tests by noise measures.

Although the dependent variable percent correct appears to be the better measure of performance (more variability accounted for than the dependent variable time taken to complete) during given conditions, in both instances, a similar order of predictive capacity of independents was found (see Table 15). For the dependent percent correct, the order of strength in prediction began with *endurance* (R^2 = .387), followed by *session* (R^2 = .151), then *absorbed power* measure (R^2 = .114), next *exposure limit* criteria (R^2 = .112), and finally *noise* (R^2 = .069). For the dependent time taken, the order of independents was *endurance* (R^2 = .380), followed by *session* (R^2 = .091), then *absorbed power* measure (R^2 = .073), next *exposure limit* criteria (R^2 = .038), and finally *noise* (R^2 = .025).

Table 15

Predictive "Weights" of Five Independents on Dependents
Percent CORRECT and TIME Taken

Percent CORRECT	TIME taken
Percent correct = .931 - .001 * Endur; R^2 = .387	Percent time = .323 + .001 * Endur; R^2 = .380
Percent correct = .881 - .046 * Sess; R^2 = .151	Percent time = .433 + .028 * Sess; R^2 = .091
Percent correct = .734 - .03 * Ab pwr; R^2 = .114	Percent time = .519 + .019 * Ab pwr; R^2 = .073
Percent correct = 1.43 - .008 * Exp L; R^2 = .112	Percent time = .151 + .004 * Exp L; R^2 = .038
Percent correct = .594 + .003 * Noise; R^2 = .069	Percent time = .601 - .002 * Noise; R^2 = .025

Seat Cushion Attenuation

One logical question to ask is whether seating used for this experiment (foam cushioned) dampened (attenuated) vibration experienced by test participants. This question may be resolved using a graph created by Goldman and Von Gierke (1960), delineating static deflection of a mass on a spring (such as a man on a seat cushion) as a function of the natural frequency. Figure 29 shows that to obtain a natural frequency for the man-seat system lower than the resonant frequency of the man alone (5 cps) requires a large static deflection. For the current study, with 4-inch (easily compressible) maximum foam padding in each test participant's seat, attenuation in cycles per second of (natural) frequency through static deflection might be compared to being modified by a difference of 1.6 cps. As the vibration maximum cycles per second frequency recorded in the present study did not approach human body resonance for an extended period (only 20 to 30 minutes maximum per session), it would appear that no "significant" vibratory attenuation should be attributed to the seating used. Additionally, the literature states that a vehicle passenger type seat cushion does not alter the resonant frequency of the man-seat system significantly, so that little or no isolation is achieved in the frequency range below 5 cps. However, damping properties of the seat cushion are important in attenuating the frequencies above resonance.

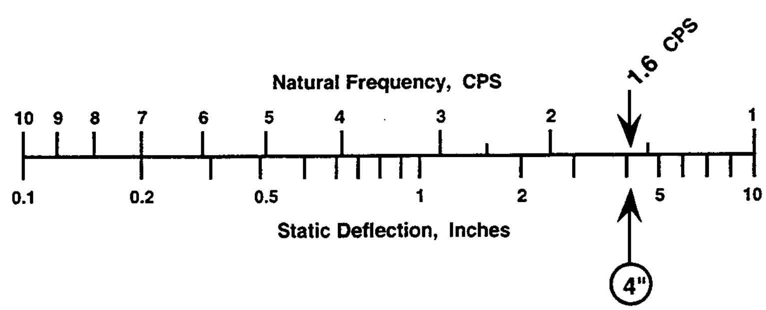


Figure 29. Static deflection of a mass as a function of natural frequency.

DISCUSSION

This field exercise was conducted to expand the database in support of future Army C^2 operations. Newer doctrine mandates that TOCs be completely mobile, capable of movement as required by the battle rather than anticipating 4+ hours of stationary periods as is current. Specifically, queries posed were to determine which human cognitive aspects deteriorate as a function of the environment, the time and location these instances occur, and to estimated the weight of environmental affectors contributing to human cognitive performance degradation. Such knowledge will assist systems designers in modeling performance parameters, for input to operational doctrine for the C^2V once fielded. Thus, tasks posed became an assessment of the genus and degree of human performance degradation. Employing Fleishman's taxonomy of *cognitive skills and experiences* (Fleishman & Quaintana, 1994), six concepts of greatest concern (selected as most important in a TOC environment) were elected for observation, and the selection of tests for these capable of evoking valid results in a robust environment was followed. With this, operator-perceived stress was also assessed by administering an ARL modified battery of paper and pencil stress measures coupled with one physiological measure referred to as amylase enzyme assay. The lack of an available C^2V necessitated that an experimental vehicle similar to an actual C^2V be used, given that this platform displayed the normal characteristics of a militarized tracked vehicle.

The primary objective of quantifying operator cognitive performance degradation in an off-road environment was approached by repeatedly administering a battery of cognitive assessments. A secondary objective was to evaluate the psychometrics used. The preceding was done to assess operator cognitive degradation over time and to estimate the effect of the stressors, referred to as *endurance* while mobile, tracked vehicle *vibration*, and vehicular *noise*. The latter was performed to gain knowledge to the capability of conducting such an assessment for use in future exercises. The researchers hypothesized that cognitive performance would degrade over time because of all stressors and that this could be defined, measured, and perhaps predicted.

A modified M113 (current issue U.S. Army APC) was used as the experimental platform, and the method employed was to administer the batteries of cognitive tests and stress assessments throughout the day. Tests batteries were administered in periods eight times per day per subject; these periods are called *sessions* in this report. Each session was approximately 40 minutes long, after which, stress measures were given. Conditions were varied. All odd numbered sessions were conducted while the vehicle remained stationary with the engine and generator operating (allowing some small degree of vibration to be recorded). Sessions 2 and 6 were conducted while the vehicle traversed a test track at an approximate speed of 10 mph, and Sessions 4 and 8 were conducted with an increase of speed to a little more than 20 mph (speeds were used to generate a range of vibratory levels). These 0-, 10-, and 20-mph speeds are referred to as *condition*.

Cognitive test performance criterion variables were (a) percent <u>correct</u> (average correct answers per test), and (b) <u>time</u> taken to respond to questions (the average taken of the time allowed per question). The cognitive concepts measured were (a) *selective attention*, (b) *inductive* *reasoning*, (c) *time sharing*, (d) *memorization*, (e) *spatial orientation*, and (f) *speed of closure*. Computer-based psychometrics selected to evaluate these concepts were, respectively, (a) the "Continuous Recall Task," (b) the "Mathematical Processing Task," (c) the "Grammatical Reasoning Task," (d) "Sternberg's Memory Search," (e) the "Route Planning" test, and (f) the "Missing Items" test.

For the purposes of measuring vibration, two types of ride quality analysis were performed. The first technique involved integrating PSD data over frequency bands corresponding with those in ISO Standard 2631/1-1985(E) (which enables numerical limits for exposure to vibration, defining these in terms of reduced comfort, fatigue-decreased proficiency, and total exposure). The second technique required determining the power absorbed by the seated test participant (measuring the rate at which vibration energy was absorbed by the human). Noise levels were measured at the ear, using a microscopic microphone implanted in a hollowed ear plug, since most important to consider was sound level transmitted to participant's ear. A total of 18 test participants volunteered, ranging in age from 21 to 34, all with military and computer usage experience. Although participants were required to complete 5 hours of training before their day of testing, training was repeated each morning before test initiation to reduce the effects of learning. Testing was not initiated until the first hour (plus) of each morning had elapsed, during which time, participants were required to ride in the vehicle to allow them to become acclimated to vibration conditions. No subject reported episodes of motion sickness at any time during testing.

Results found the tests of cognitive performance selected to be capable of measuring their associated cognitive concept, as was seen by degrees of performance degradation resulting among each.

The cognitive tests that were administered significantly differed among tests and between sessions. As such, performance of the cognitive concepts differed. Performance in tests was significantly affected by the session in which they had been administered. This was found representative for both dependent variables percent <u>correct</u> ($p < 0.001$) and <u>time</u> taken to complete tests ($p < 0.001$). During most instances, test performance decreased and time to complete tests increased as the day lengthened. It can be seen that the effect of vibration contributed to decrements in test performance by the statistical significance achieved between most tests when a session including vibration occurred.

In determining when effects took place, performance in all tests degraded significantly (from baseline) at Session Number 4 (the first exposure to the greatest degree of vibration).

Differences (from initial session) generally began to appear at this session, normally reappearing at Session Number 6 (participants' second exposure to medium vibration) and generally continued to degrade through the remaining two sessions until the end of the day. Session Number 4 took place approximately between the 220th and 275th minutes of testing, about the fourth hour into the test day.

Comparing test means for percent correct collectively, the greatest degree of test difficulty experienced appears to have been with the test measuring the concept *spatial orientation* (Route Planning). This was followed in difficulty by the tests measuring *memorization* (Sternberg's Memory Search Task) and *speed of closure* (Missing Items). Greater overall test difficulties were recorded for the tests measuring the concept *inductive reasoning* (Mathematical Processing Task), next the concept *time sharing* (Grammatical Reasoning Task), and finally least recorded for the test measuring the concept *selective attention* (Continuous Recall Task), apparently the easiest of all to perform.

In recording times taken of the given amount allowed per test, the greatest degree of test difficulty was seen for the test measuring the concept *spatial orientation* (Route Planning), followed almost equally by the test measuring the concept *inductive reasoning* (Mathematical Processing Task). The test measuring the concept *memorization* (Sternberg's Memory Search Task) took third longest to complete, followed by the test measuring the concept *speed of closure* (Missing Items). The test measuring the concept *time sharing* (Grammatical Reasoning Task) took less time to complete, and finally the test measuring the concept *selective attention* (Continuous Recall Task) took least.

However, although differences found between test means (test difficulty) are important, of greater concern is the amount of preformance decrement found *within* concepts. The greatest regressive degree of test difficulty experienced by participants when measuring percent correct (given the environment subjected to) was with the concept *time sharing* (the Grammatical Reasoning Task). This was followed closely by the concepts *selective attention* (the Continuous Recall Task) and *inductive reasoning* (the Mathematical Processing Task), followed closely by the the concept *spatial orientation* (the Route Planning Test), then the concept *speed of closure* (the Missing Items Test), and least deviation was seen for the concept *memorization* (Sternberg's Memory Search Task). Measuring time taken to complete, greatest deviancy (degree of difficulty) was found for the concept *speed of closure* (the Missing Items Test), followed by the concept *time sharing* (the Grammatical Reasoning Task), then by the concepts *inductive reasoning* (the Mathematical Processing Task) and *spatial orientation* (the Route Planning Test), then the concept *selective attention* (the Continuous Recall Task), and finally least affected by the environment appears to have been the concept *memorization* (Sternberg's Memory Search Task).

The test measuring the concept *time sharing* followed the pattern of other tests, although with slightly lower performances recorded at each session, beginning at a baseline performance of 92% and falling to 46% performance by day's end (a 46% decrease). Significant decrement in performance began at Session Number 6 (the second 10-mph vibration exposure) and continued through to the end of the day. As for time to complete, this test began with a baseline average slightly higher than the preceding test (43%) but ended with a final average slightly lower (70%). Although remaining stable throughout most of the day, average time to complete began rising at Session Number 5 (the third 0-mph vibration exposure) and jumped significantly to worst at Session Number 8 (the second 20-mph vibration exposure), a 27% increase in times to complete over the day.

The test measuring the concept *inductive reasoning* mimicked performance in tests selective attention and time sharing, recording performances lower than both at each session and ending with performance similar to time sharing (a performance degradation of 37% from a baseline measure of 87%, down 50% at day's end). Significant performance degradation was seen at all sessions where participants were exposed to vibration. As for times to complete, this test began with a baseline similar to memorization (60%), showed increases at Sessions Number 2 (the first 10-mph vibration exposure) and 3 (second 0-mph vibration condition), then significantly increased jumping to 84% of allowed time taken to complete this test by Session Number 8 (second 20-mph vibration exposure and at the end of the day). Total increase in time to complete this test over the day was 24%.

The test measuring the concept *spatial orientation* produced the most erratic results of all tests. Beginning at a baseline performance average of 57%, this rose at Session 3 (the second 0-mph vibration exposure). At Session Number 6 (the second 10-mph vibration exposure), performance fell significantly to the lowest of all tests, then began to climb at Session 7 (the third 0-mph vibration exposure) and fell again to end at 21% (a 36% decease in performance). Times to complete for this test began with the highest baseline recorded of all tests (65%) and ended with highest times to complete (88%). Averages were most sporadic. Times decreased at Session Number 3 significantly (the second 0-mph vibration exposure), then markedly increased by Sessions Number 5 (the third 0-mph vibration exposure) and 6 (the second 10-mph vibration exposure). A decrease was seen at Session Number 7 (the third 0-mph vibration exposure), but this rose again to highest by Session Number 8 (the second 20-mph vibration exposure and at the end of the day). Total increase in average time to complete for this test over the day was 23%.

The test measuring the cognitive concept of *memorization* remained most consistent throughout the day. Beginning with a baseline average performance of 64%, this fell to 43% by the end of the day (a 21% decrease in performance). Performance decrement became significant at Session Number 6 (the second 10-mph vibration exposure), then fell dramatically at Session Number 8 (the second 20-mph vibration exposure). Times to complete for this test also remained most consistent of all tests throughout the day. Beginning with a baseline time to complete of 59%, time rose only to 66% by the day's end (a 7% increase). Significant increases in test times were seen at the final three vibration exposures.

The test measuring the concept *selective attention* resulted in highest baseline performance scores (98% correct) followed by a fall in performance over sessions to 61%, a 37% decrease from baseline. Some effect of vibration appeared at Session Number 2 (the first 10-mph vibration exposure), then a significant fall occurred at Session 4 (the first 20-mph vibration exposure), and finally a dramatic performance decrease was measured from Session 6 (the second 10-mph vibration exposure) through the end of the day. This test also displayed lowest and most stable test time completion record, until Session Number 6 (second 10-mph vibration exposure) where time increased significantly. Time to complete then decreased somewhat but jumped significantly to highest by Session Number 8 (the second 20-mph vibration exposure). Although lowest overall times to complete were recorded for this test, times rose from a baseline of 19% to 40% by the end of the day (an increase of 21%).

The test measuring the concept *speed of closure* resulted in performance scores of less than the preceding three tests; however, performance here began to decline significantly at Session Number 5 (the third 0-mph vibration exposure) and steadily declined from here. Scores fell from a baseline average of 76% to 42% by the end of the day (a 34% decrease in performance). For times to complete, this test began with the second lowest baseline average of 37%, rising to 77% by end of day. Performance remained somewhat stable until Session Number 5 (the third 0-mph vibration exposure) when a rise in time to complete became noticeable and the increase continued. The test ended with the third longest average times to complete of all tests (an increase of 40% over the day).

Other than for tests measuring the concepts *speed of closure* and *selective attention*, the results changed, depending on the method of measurement (*speed of closure* was a poorer performer if measured by percent correct rather than time to complete, and *selective attention* was a poorer performer if measured in the reverse). The remaining concepts followed a pattern in which performance (considered less deviation measured) as *time sharing* was the concept least affected by the environment, followed by the concept *inductive reasoning*, then by *spatial orientation*, and finally, the concept *memorization* which was most affected. At all times, performance in all tests significantly decayed by Session Number 6 (the second exposure to 10-mph vibration and approximately the fourth hour of each day).

The results of a typing test, given while subjects were traveling at the highest speed, were compared to typing performance while stationary. These results revealed that it was (statistically) significantly more difficult to type while traveling. This naturally was expected but had to be recorded, as typing performance is an issue in a mobile military environment since messages are often sent in this fashion.

Concerning the stress assessment performed, psychological questionnaires administered to measure stress perceptions of participants revealed that subjects reported little or no stress before operations began. The levels reported were not significantly different than those of an independent control group. Also, during test sessions, there were no significant differences as compared to an independent control group. These results may be attributable to participants possessing sufficient familiarity with their tasks and maintained adequate ability to comprehend these, which enabled them to perform comfortably. Conversely, results obtained may reflect the different situations in which assessment measures were administered. One (cognitive) subtest of both the cognitive assessment and of the stress battery administered was the "Continuous Recall" task. Of the nine times this subtest was administered by paper and pencil method while participants were stationary (as part of the stress assessment), no significant results (degradation in performance) were found. However, when this subtest was given as part of the cognitive assessment via computer during varying conditions of vibration (movement), significant performance decrements were found when compared to participants' baseline measure. Results may also differ as a function of baseline measures used. In the stress evaluation, results are compared with a baseline established by a different group, as opposed to the cognitive assessment which used a baseline derived from current participants. In either event, it must be said that the effect of vehicle vibration could not be identified as a perceived stressor or that the sensitivity of stress measures administered did not detect this.

Cognitive test performance during varying conditions of movement (vibration) was shown to decrease because of all stressors (endurance, vibration, noise) having a significant effect on performance. However, the stressor *endurance* (measured as time in the vehicle) had greatest effect. To determine when this occurred, testing was divided and measured by *sessions* (test periods 1 through 8 of each day), which became the second greatest measure affecting performance. Actual measures of vibration, *absorbed power* recordings and *exposure limit* criteria, followed in strength as predictors of performance, although the absorbed power method was found slightly better in predicting dependent variables. Least affecting performance (yet significant) was the stressor *noise*.

Observed collectively, the predictor variables *endurance*, *session*, *absorbed power*, *exposure limit,* and *noise* returned a multiple R value for the variable% correct of .733 ($p < .0001$) and for the dependent variable time to complete of .649 ($p < .0001$). For the dependent% correct, the order of strength in prediction began with *endurance* ($R^2 = .387$), followed by *session* ($R^2 = .151$), then *absorbed power* measure ($R^2 = .114$), next *exposure limit* criteria ($R^2 = .112$), and finally *noise* ($R^2 = .069$). For the dependent time taken, once again the order of independents was *endurance* ($R^2 = .380$), followed by *session* ($R^2 = .091$), then *absorbed power* measure ($R^2 = .073$), next *exposure limit* criteria ($R^2 = .038$), and finally *noise* ($R^2 = .025$).

Guinard (1965, 1972) showed that vibration may degrade performance either by disruption at the point of contact between soldier and task or by the distraction of cognitive processing. Most studies have reported on discrete frequency, sinusoidal, constant intensity motion. In reality, vibration is usually random in frequency and amplitude, and peak energy most likely occurs at several frequencies, especially those where greatest human performance decrements are known to occur (the low frequency range, per Goldman and von Gierke, 1960). Hornick, Boettcher, and Simmons (1961) write that in most ground vehicles, the vibration imparted to human occupants has characteristics of low frequencies and high amplitudes, rendering observance of this highly important.

The detrimental effect of noise as additive is consistent with results of other studies (Harris, Chiles, & Touchstone, 1964; Shoenberger, 1967; Weisz, Goddard, & Allen, 1965), although it should be noted that the effect of noise on performance was small in relation to that of other stressors assessed.

It was expected that the absorbed power recordings method accounted slightly better for performance than did the exposure limit criteria, as the latter is often exceeded in studies of the effects of vibration. Among other researchers, Guinard, Landrum, and Reardon (1976) found no significant change in performance scores during human exposure to vibration levels for exposure as long as 8 hours. They concluded that the standard might be unduly conservative, postulating that it is so because it is based on extrapolation from various mega data sources. An alternate hypothesis may be that this standard is often used for comparison by researchers conducting vibration studies using young, physically fit military personnel. Such test participants should be capable of withstanding greater exposures before showing performance decrements than would a true sample of the general civilian population, and these test participants are accustomed to doing so as is common with members of the armed services.

Cumulative effects of the episodes of vibration exposure were seen in this study, since performance was never as great as baseline during latter-day sessions even when vibration was not present. Such would be the case in a mobile command center. Here, one should expect operators to respond more slowly than normal (especially when hasty decisions are required of vehicle occupants), after vibration experiences.

Decrements in cognitive performance attributable to vibration have been found by most researchers, yet few others have not. Results where complex tasks were used suggest that there may be disruption of cognitive performance. Huddleston (1974) and Sandover and Chapman (1984) found vibration-related decrements in information processing using a mental arithmetic task. A similar performance loss was identified by Shoenberger and Harris (1965) using a complex counting task. The findings of no such effects using memory scanning measures would appear to conflict with these results.

It is reasonable to assume cognitive decrement can be measured. Shoenberger (1974) states that the Sternberg task can be successfully used in vibration environments to identify vibration effects with respect to human information processing states and that it is apparently a sensitive instrument for detecting visual interference attributable to vibration. Results acquired during the current test show other cognitive psychometrics to perform similarly, and with even greater sensitivity, especially after prolonged and sporadic exposure epochs. The rationale for this may be that more sensitive tasks were used for measuring performance here, or that complex waveform vibration was used in the present effort (0.88 *g* by 3 cps at 20 mph, 0.65 *g* by 4 cps at 10 mph, and 0.03 *g* by 12.5 cps at 0 mph) rather than sinusoidal as used in most previous experiments.

The trend of the data suggests that had testing continued for a longer period of time, the trials effect would have been significantly greater. Although there is little evidence to support this assumption, it is a possibility since the ISO standard for vibration exposure (International Organization for Standardization, 1974) assumes that vibration affects performance intensively as a function of duration. Various type functions (linear, log, exponential, and power) could be applied to the data to determine which best describes the decay in performance in terms of fitting and the reasonableness of extrapolations to longer time periods, but here it can be comfortably stated that any greater decrement would only contribute to already poor performance. Thus, it is possible to infer some tentative answers to questions concerning projected effects.

This investigation also showed the existence of dose-response relationships, a higher dose of vibration associated with more unfavorable effects. Additionally, the trials effects recorded indicate that performance deteriorated as a function of time in the environment, usually at the fourth hour. With knowledge that such measurements can be made, and given insight to the additional cognitive demands to be placed on future commanders required to make sporadic movements, these added skills must be assessed in the future.

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APPENDIX A

FLEISHMAN'S DEFINITIONS

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MEMORIZATION is the ability to memorize and retain new information which occurs as a regular or routine part of the task. These new bits of information must be memorized to properly accomplish or carry out the task. This ability does not extend either to the memorization of the task procedures or to the recall of any information previously learned outside of the given task situation. [update] The ability to remember information, such as words, numbers, pictures, and procedures. Pieces of information can be remembered by themselves or with other pieces of information.

SELECTIVE ATTENTION is the ability to perform a task in the presence of distracting stimulation or under monotonous conditions without significant loss in efficiency. When distracting stimulation is present in the task situation, it is not an integral part of the task being performed, but rather is extraneous to the task and imposed upon it. The task and the irrelevant stimulation can occur either within the same sense or across senses. Under conditions of distracting stimulation, the ability involves concentration on the task being performed and filtering out of the distracting stimulation. When the task is performed under monotonous conditions, only concentration on the task being performed is involved. [update] The ability to concentrate on a task one is doing. This ability involves concentrating while performing a boring task and not being distracted.

SPATIAL ORIENTATION is the ability to *maintain one's orientation* with respect to objects in space or to *comprehend the position* of objects in space with respect to the observer's position. The question posed is often "If the environment looks like this, what is my position?". [update] The ability to tell where you are in relation to the location of some object or to tell where the object is in relation to you.

INDUCTIVE REASONING is the ability to find the most appropriate general concepts or rules which fit sets of data or which explain how a given series of individual items are related to each other. It involves the ability to synthesize disparate facts; to proceed logically from *individual cases to general principles.* It also involves the ability to form hypotheses about relationships among items or data. [update] The ability to combine separate pieces of information, or specific answers to problems, to form general rules or conclusions. It involves the ability to think of possible reasons for why things go together.

TIME SHARING is the ability to utilize information obtained by shifting between two or more channels of information. The information obtained from these sources is either integrated and used as a whole, or retained and used separately. [update] The ability to shift back and forth between two or more sources of information.

SPEED OF CLOSURE ability involves the speed with which a set of apparently disparate sensory elements can be combined and organized into a single, meaningful pattern or configuration. The operator must combine *all* the elements presented from a single source of information into a meaningful configuration. The operator is *not told* what he or she is trying to identify; the elements appear to be disparate. This ability applies to all senses with the restriction that elements to be combined must be presented within the same sensory modality. [update] Involves the degree to which different pieces of information can be combined and organized into one meaningful pattern quickly. It is not known beforehand what the pattern will be. The material may be visual or auditory.

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APPENDIX B

TEST PARTICIPANT QUESTIONNAIRE

TP # __________ Date __________

TEST PARTICIPANT QUESTIONNAIRE [POST-test responses]
(given to participants to complete)

Did you have any particular problems with any part of this exercise:

(please explain)..

....

....

Did you understand what you were to do for all of the tests given:

☐ YES ☐ NO

(please explain)..

....

....

Did you have any problem with the vehicle, such as:

☐ not enough air ☐ claustrophobic feeling

☐ uncomfortable ride ☐ too much vibration

(please explain)..

....

....

Did you have any problem with the computer equipment you used, such as:

☐ keeping your fingers on the keys ☐ too much shaking

☐ seeing the computer screen ☐ too much noise

☐ hitting the wrong keys ☐ not enough light

(please explain)..

....

....

Are there any comments <u>or</u> suggestions you would like to make:

....

....

....

....

....

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THANK YOU for your participation!

APPENDIX C

DEMOGRAPHIC SURVEY

DEMOGRAPHIC SURVEY
[PRE-test responses]
(read to participants and completed by experimenter)

TP I.D. #............................ Date ....

Age .... Sex ....

MOS .... # Years in Army ....

How many hours per week do you use a computer at home or at work ....

How many hours have you spent in a moving tracked vehicle this year ....

Have you ever been motion sick or sea sick:

☐ YES ☐ NO

Has this happened often (please explain)...

....

....

When and where did/does this happen ....

....

....

To the best of your knowledge, do you have, or have you ever had:

☐ BREATHING problems ☐ HIGH BLOOD PRESSURE

☐ SEIZURES ☐ VISION problems

☐ CLAUSTROPHOBIA ☐ ALLERGIES

☐ EAR disorders ☐ STOMACH problems

If you answered yes to any of the above, have you had this/these:

☐ Often ☐ Occasionally ☐ Seldom

Comments ....

....

Have you ever had experience working in a Tactical Operations Center (TOC)?:

☐ YES ☐ NO

If "YES", please explain: ....

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13. ABSTRACT *(Maximum 200 words)*

Operator cognitive performance was quantified in an off-road environment by repeatedly administering a battery of cognitive measures to assess the genus and degree of performance while mobile. Environmental stressors referred to as endurance, tracked vehicle vibration per intensity, and noise were recorded over the course of one day per participant (n=18). Vibration conditions presented were varying amplitudes approximating accelerations of 0.88 g by a frequency of 3 cycles per second (cps), 0.65 g by 4 cps, and 0.03 g by 12.5 cps. Observed collectively, the predictor variables returned a multiple R value for the dependent variable percent correct of 0.733 ($p < .0001$) and for the dependent time to complete of 0.649 ($p < .0001$). Although all stressors significantly influenced performance, uncovered was a repeated order of effect per method of evaluation, beginning with the measure endurance, then session, followed by absorbed power recordings, then exposure limit criteria comparison, and finally, noise. Cognitive performance decrement measured as percent correct was found for the cognitive concepts time sharing, selective attention, inductive reasoning, spatial orientation, speed of closure, and memorization. Measured as percent of time taken to complete tests, degradation was found for the concepts speed of closure, time sharing, inductive reasoning, spatial orientation, selective attention, and memorization. This investigation displayed the existence of dose response relationships, higher doses of vibration associated with more unfavorable effects. Additionally, the trials effect recorded indicates that performance deteriorated as a function of time in the environment.

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