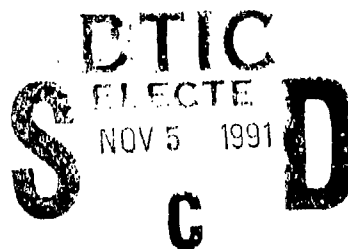


ARI Research Note 91-90



①

Fatigue Effects on Human Performance in Combat: A Literature Review

AD-A242 887



Susan M. Evans

Vector Research, Inc.

Robert R. Mackie and C. Dennis Wylle

Essex Corporation

for

**Contracting Officer's Representative
David Promisel**

**Manned Systems Group
John L. Miles, Jr., Chief**

**Systems Research Laboratory
Robin L. Keesee, Director**

August 1991



91-15014



**United States Army
Research Institute for the Behavioral and Social Sciences**

Approved for public release; distribution is unlimited.

● 1 1104 095

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction
of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

MICHAEL D. SHALER
COL, AR
Commanding

Research accomplished under contract
for the Department of the Army

Vector Research, Inc.

Technical review by

Donald B. Headley

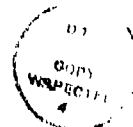
Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

NOTICES

DISTRIBUTION: This report has been cleared for release to the Defense Technical Information Center (DTIC) to comply with regulatory requirements. It has been given no primary distribution other than to DTIC and will be available only through DTIC or the National Technical Information Service (NTIS).

FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The views, opinions, and findings in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other authorized documents.



REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS ---		
2a. SECURITY CLASSIFICATION AUTHORITY ---			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE ---					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) VRI-ARI-9 FR89-1(R) Vol. I			5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Note 91-90		
6a. NAME OF PERFORMING ORGANIZATION Vector Research, Incorporated		6b. OFFICE SYMBOL (if applicable) ---		7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute Manned Systems Group	
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 1506 Ann Arbor, MI 48106		7b. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences		8b. OFFICE SYMBOL (if applicable) PERI-S		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MDA903-86-C-0428	
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO. 62785A	PROJECT NO. 791	TASK NO. 353	WORK UNIT ACCESSION NO. C01
11. TITLE (Include Security Classification) Fatigue Effects on Human Performance in Combat: A Literature Review					
12. PERSONAL AUTHOR(S) Evans, Susan M. (Vector Research, Inc.); Mackie, Robert R.; and Wylie, C. Dennis (Essex Corporation)					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM 86/09 TO 88/10		14. DATE OF REPORT (Year, Month, Day) 1991, August	
15. PAGE COUNT 253					
16. SUPPLEMENTARY NOTATION Essex Corporation is a subcontractor for Vector Research, Inc. Contracting Officer's Representative, David Promisel.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Human performance Sustained operations		
			Combat models Fatigue		
			Continuous operations Physical stress		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) For this report, a literature review was conducted to assess the knowledge of the effects of fatigue and related stressors on the performance of military personnel engaged in diverse military tasks. The objective was to determine whether there are sufficient objective, quantifiable data on the effects and time-course of fatigue to justify incorporation into combat models. Both mental and physical fatigue were considered. More than 500 articles, reports, and books were reviewed for this effort. A summary table of the results of sleep deprivation studies was organized. Prediction equations for physical activity are discussed.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL David Promisel			22b. TELEPHONE (Include Area Code) (202) 274-6917		22c. OFFICE SYMBOL PERI-SM

FATIGUE EFFECTS ON HUMAN PERFORMANCE IN COMBAT: A LITERATURE REVIEW

CONTENTS

	Page
INTRODUCTION	1
Background	1
Approach	1
Research Results	4
Conceptual Framework	4
Literature Review	5
NTC Research	6
LITERATURE REVIEW	7
Document Users	10
Report Organization	11
APPROACH	12
Screening Procedure	12
Review Criteria	13
RESULTS FROM A REVIEW OF THE LITERATURE	15
Introduction	15
General State of Knowledge	15
Effects of Fatigue and Sleep Loss in Specific Functions	19
Other Literature Reviews	26
CONCLUSIONS	30
State of Knowledge	30
Impact of Fatigue on the Combat Process	39
APPENDIX A. FULL SYNOPSES OF RELEVANT REPORTS	A-1
B. ABBREVIATED SYNOPSES OF RELEVANT REPORTS	B-1
C. ANNOTATED BIBLIOGRAPHY	C-1

CONTENTS (Continued)

Page

LIST OF TABLES

Table 1. Experiment summary table	31
---	----

LIST OF FIGURES

Figure 1. Framework of variables and relationships for considering human variables in combat models	9
--	---

**FATIGUE EFFECTS ON HUMAN PERFORMANCE IN COMBAT:
A LITERATURE REVIEW**

INTRODUCTION

Background

This report constitutes a literature review, conducted as part of research performed for the U.S. Army Research Institute for the Behavioral and Social Sciences (USARI) under the terms of contract number MDA903-86-C-0428. The research, entitled "Building Human Variables into Combat Models," was performed by a team led by Vector Research, Incorporated (VRI) as prime contractor, with Horizons Technology, Incorporated (HTI) and Essex Corporation as subcontractors. The research was initiated in September 1986. Dr. David M. Promisel of USARI Systems Research Laboratory was the Contracting Officer's Technical Representative (COTR). Dr. Irving Alderman served as deputy COTR and made significant contributions to the research directions and the research itself.

The objectives of the research associated with "Building Human Variables into Combat Models" derived from perceived shortcomings of the combat models and analyses performed in support of Army decision making, and from the expectations that "soldiers on future battlefields will experience: high lethality, high disability, high stress, significant casualties in rear areas, severe sleep deprivation, low light levels, and operations during normal sleeping hours."^{**} The technical objectives as provided in the Statement of Work were "to identify human variables that are expected to influence predictions of combat effectiveness, to develop procedures for measuring these variables and collecting data, and then to estimate the nature and level of their effects." Research performed by the team to accomplish these objectives is summarized in this introduction. This volume presents the results of the literature review.

Approach

Two principal tasks were included in the research program. The first task was to develop a conceptual framework "for inquiry identifying the range of variables to be examined and the types of hypotheses to be investigated". This development required that the following factors be addressed:

- (1) level of detail (e.g., global versus mission versus task-specific);

^{*}Cherry, W.P., Davis, R.E., Brecht-Clark, J. (1988). Building Human Variables into Combat Models (ARI Research Note). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (In process)

^{**}DePuy, William, "Concepts of Operation: The Heart of Command, The Tool of Doctrine", Army, August 1988, pp. 26-40.

- (2) scope (e.g., type of terrain and/or mission, nature of enemy threat); and
- (3) anticipated complexity (e.g., simple "decrement" factors to adjust soldier performance under specified conditions such as fatigue versus more complex sets of relationships with multiple interacting variables.

The development of a preliminary version of the conceptual framework was the first subtask in the research program. It was based upon review of material from three sources: (1) a subject matter expert with extensive experience in combat, in training, and in command; (2) anecdotal accounts of battle, including autobiographical and biographical literature and military history; and (3) the behavioral science literature. The development also drew on the experience of the research team with the National Training Center (NTC) and with combat modeling and analysis.

The review of the behavioral science literature constituted the second subtask, and it was given a particular focus and scope, namely, it was restricted to material related to fatigue and its role in combat. This approach was adopted for a number of reasons. First, the nature of combat envisioned by AirLand Battle Future involves continuous, high stress operations and understanding fatigue is very important. Second, a series of field studies involving fatigue were scheduled to occur during the period of the contract, and it was hoped that these experiments could be utilized in a serendipitous manner.

The literature on fatigue and related stressors likely to be encountered in the battlefield is enormous, but much of it is not helpful from the viewpoint of performance problems posed by continuous operations. To constrain the literature search, which included the data bases of the Defense Technical Information Center (DTIC), and the National Technical Information Service (NTIS), we employed a strategy that required report titles to include not only key terms such as fatigue and/or stress, but also performance. Special searches were also conducted on "human variables in combat", "combat fatigue", and "combat stress". These initial searches, plus a sizable reference list of our own on fatigue and other stressors, created a large inventory of possibly relevant articles and technical reports. Titles and abstracts were then thoroughly screened for apparent relevance to long term performance, loss of sleep, and other stressors likely to be encountered in a combat environment (e.g., heat, noise, vibration, enemy action). This search procedure was generally followed until the reference lists of newly acquired documents showed a high degree of overlap with those previously acquired.

Data bases of DTIC and NTIS, as well as MedLine were searched for studies involving physical fatigue and related stressors. Relevant areas in this search included physiology, muscle strength, endurance, and rest and recovery periods. While reports of studies involving continuous operations and physical work from the military community were preferred, relevant industrial or laboratory studies involving repetitive manual materials handling, heavy physical work, physical work capacity, and heat stress were also considered.

The third and final subtask was to refine the preliminary conceptual framework. This subtask was originally intended to be based on "findings from the literature review and input from recognized military/research authorities". Both these sources were used, however, results of research performed at NTC also played a significant role in determining the final form of the framework.

The second principal task of the research program was the estimation of the effects of specified human variables on the combat process. It included the development of testable models and hypotheses, preparation of a research plan, development of data collection instruments and procedures, implementation of the research plan, and synthesis of the research findings. These five subtasks were completed in the context of a particular rotation at NTC and focused on the impact of sleep-loss and fatigue on combat effectiveness.

The rationale for choosing an NTC rotation as a research vehicle was related to an opportunity to "piggyback" on other research scheduled well before the initiation of this study. For the rotation in question, the Walter Reed Army Institute of Research (WRAIR) had instrumented 68 soldiers (primarily members of the battalion staffs, the company, and the platoon leaders) with wrist monitors which measured activity as a function of time over the 14 days of the rotation. For the same rotation, the Leadership and Management Technical Area of the USARI Training Laboratory conducted research on platoon leadership. It was the opinion of the research team that, if the NTC digital data base, After Action Reviews (AAR), and Take Home Packages (THP) could be analyzed, that an understanding of the link between fatigue, leadership, and battalion effectiveness might be developed. Accordingly, research plans were prepared to investigate the link between fatigue and platoon leadership using WRAIR and Leadership and Management Technical Area results* and to investigate the links between fatigue and combat effectiveness using WRAIR data, Leadership and Management Technical Area data, and digital data, AAR, and THP from NTC.**

HTI examined the observer controller and subject matter expert data and the WRAIR sleep data to assess if there was a tie between sleep patterns/levels and the subjectively rated unit performance. HTI also examined pre- and post-rotation questionnaires and the resulting data on leadership, attitudes, commitment, morale, training adequacy, training quality, and demographics on military and unit history and responsibilities to assess possible relationships between sleep patterns and experience, longevity in the unit, and unit leadership ratings.

*Horizons Technology, Incorporated (1987). Research Plan for Examining the Effects of Sleep Loss on Leadership and Unit Performance at the NTC. Oakton, VA: Horizons Technology, Incorporated.

**Davis, R. (May, 1988). NTC Data Base Analysis (VRI-ARI-9 WN88-1(R)). Ann Arbor, MI: Vector Research, Incorporated.

The approach proposed for the analysis of NTC data centered on the concept of minibattles, derived from Rowland,* and synchronization** both consistent with the early versions of the conceptual framework. Synchronization provided a basis for investigating a series of hypotheses. The research plan focused on the digital data base but included analysis of AAR and THP. It also included participation by TRADOC Analysis Command, White Sands Missile Range (TRAC-WSMR), as a source of terrain and line-of-sight analyses.

Research Results

The results of the research program fall into two categories. The first category encompasses the conceptual framework and the associated literature review. The second category includes the hypotheses and models derived from the conceptual framework and the research carried out on the NTC rotation. The results are summarized as follows.

Conceptual Framework

The conceptual framework has two principal components. The first embodies a perspective of combat which views the combat process as resulting from the activities of small units, groups, or teams -- the executing elements of vertical functional systems or battlefield operating systems. Two types of small units, groups, or teams are included: one that is an executing element and one that provides command and control -- both vertical and horizontal. The framework thus addresses all levels of combat from squad to theater and emphasizes both performance of tasks and missions and the degree to which synchronization is present among different elements of a vertical functional system and between elements of different vertical functional systems. This choice of "level of resolution" is based upon a requirement to represent the fact that not all subunits of, for example, battalion, brigade, or division, are equally capable or at any given time equally influenced by human variables. It also reflects an approach to determining combat effectiveness that emphasizes synchronization.

Given a particular small unit, group, or team, the impact of human variables on its performance of tasks or a set of tasks and its behavior is addressed in the second component of the framework, which is in a mathematical sense a set of conditioning arguments or implicit functions describing changes in performance and behavior over time. The first

*Rowland, D. (June, 1986). "Assessment of Combat Degradation". RUSI Journal, 33-43.

**DePuy, W. (January, 1988). "Baseline Functional, Organizational, and Procedural Structure for the Command and Control of an AirLand Battle Force in a Joint Environment". Briefing to Commander, Combined Arms Center, both consistent with the early versions of the conceptual framework. Synchronization provided a basis for investigating a series of hypotheses. The research plan focused on the digital data base but included analysis of AAR and THP. It also included participation by TRADOC Analysis Command, White Sands Missile Range (TRAC-WSMR), as a source of terrain and line of sight analyses.

"function" reflects that performance, measured in terms of task or behavior selected, and time, accuracy, and completeness of task performance, has a baseline that is a function of basic abilities, individual and collective training, cohesion and leadership, and supervision (by an internal leader). The second "function" addresses environmental stressors and postulates that exposure to these stressors together with the intensity of task performance causes changes in baseline performance. The third "function" deals with the stress-recovery process and relates changes in performance for a given set of environmental stressors to the nature of the stress-recovery process. The final "function" deals with so-called intangible factors -- morale, motivation, and leadership and is based on an assumption that these factors primarily influence performance by changing the impact of the stress-recovery process.

The conceptual framework leads to a concept for addressing human variables that involves decrement factors to be derived from the four functional forms described above, related to time. It also implies that in order to address issues of unit or formation effectiveness relative to human variables, analysts and researchers must represent the distribution of positions in stress-recovery cycles over the different executing elements and vertical functional systems.

Literature Review

The literature review served two purposes. The first was to provide insights to the development of the conceptual framework; the second was to ascertain the degree to which the literature could be used as a source of data to describe the impact of human variables in combat. As noted above, the literature review focused on fatigue and sleep-loss. In this context it supported the emphasis in the framework on the stress-recovery process and on the categorization into small units, groups, or teams. In terms of serving as a source of data, however, the review was not as useful as had been hoped.

Much of the literature concerning the effects of fatigue on human performance, including studies where military type tasks were performed as well as those employing fundamental psychological tests, have been inconclusive because of improper experimental protocol, the nature and duration of the tasks studied, and the type of test device used and when administered. Many studies do not report a baseline of performance, making it difficult to describe the effects of fatigue on performance in quantitative terms. In addition, there is very little information on the combined effects of fatigue and other battle related stressors, such as heat, cold, vibration, confinement, and noise, as well as real world adverse environments and uncertainties.

In addition to examining the behavioral science literature, anecdotal material was reviewed. The anecdotal literature is a means of establishing human behavior in combat and is useful in this regard. However, because it deals with specific combat situations it does not provide the range of situations nor the degree of control necessary to develop quantitative data regarding human variables and performance.

NTC Research

The research performed in conjunction with WRAIR and the Leadership and Management Technical Area of USARI had as its objective linking fatigue and sleep-loss to combat effectiveness through small unit leadership and battalion command and control. The results, compared to this objective, are at best ambiguous. First, not all the units had instrumented personnel. Second, for those personnel for whom data were available, it is not clear that the rest-activity patterns realized are consistent with the build-up of fatigue. Given that there is no firm evidence of fatigue, other causes must be sought to explain the combat results and unit effectiveness. In itself this proved to be useful.

The analysis of combat dynamics and unit effectiveness using the digital data base, AAR, and THP was designed to address four hypotheses:

- (1) a small unit's performance in delivering its "increment" of combat power is dominated by initial conditions which determine opportunities to participate;
- (2) determination of initial conditions is dominated by leadership and supervision;
- (3) given opportunities to participate, the level of participation by individual systems does not vary significantly; and
- (4) given a decision to participate, soldier/system contribution does not vary significantly. The quality of the digital data base precluded extensive analysis at the level of detail originally proposed.

Nonetheless, the evidence developed provides no reason to reject any of the four hypotheses. Individual system performance was shown to be at or beyond standards in such tasks as engagements. The data suggested that a fraction of systems do not participate even when given opportunities. Leadership and supervision were key to ensuring that tasks were initiated, in particular, engagement and synchronization across vertical functional systems. NTC results also provided examples of the extreme realization of hypothesis one -- units failed to contribute or contributed only marginally because they were in the wrong place at the wrong time due to command and control deficiencies.

To supplement the quantitative analysis (which relied heavily on the digital data base), a qualitative analysis of a small set of randomly chosen AAR and THP was undertaken. This analysis focused on occurrences of events which indicated failures to synchronize among the executing elements of different vertical functional systems. While the training role of NTC cannot be ignored, the analysis revealed consistent patterns of breakdowns in synchronization and suggested that the NTC data could serve as a source of baseline data for the performance of command and control elements at levels above platoon. It is this "executing control element" that is the major determinant of unit effectiveness in the rotations examined in this research.

LITERATURE REVIEW

The purpose of the review presented in this volume was to assess the state of knowledge concerning the effects of fatigue and related stressors on the performance of military personnel engaged in diverse military tasks. The objective was to determine whether there are sufficient objective, quantifiable data on the effects and time-course of fatigue to justify their incorporation into combat models. To date, combat models have been seriously deficient in their treatment of variables associated with the performance of individual soldiers who, in turn, affect the performance of units and the likelihood of larger mission accomplishment.

The principal focus of the review was on the role of fatigue in continuous and sustained military operations. However, as the review stands we believe that it broadly applies to many kinds of Army operations.

In discussing the effects of fatigue, it is important to distinguish between "mental" fatigue and physical fatigue. Mental fatigue is concerned with the individual's reduced capability for performing cognitive tasks in a timely and error-free manner. It is associated primarily with inadequate opportunities for getting the amount of sleep required to maintain high levels of alertness. Physical fatigue is a product of extended muscular effort brought about by the requirements to perform physically demanding tasks, often in physically demanding environments.*

It is apparent that both types of fatigue must be addressed in any model of continuous or sustained operations if the human element as a limiting condition of military operations is to be taken properly into account. An understanding of the types of military tasks to be performed is critical when considering the relative importance of mental and physical fatigue. It is generally agreed that mental fatigue is likely to be a serious problem in those individuals responsible for all levels of command and control, for planning, and for complex decision making. It is also critical for those persons performing tasks that are highly demanding of sustained and selective attention, and for tasks that require the learning of new material or procedures. In contrast, physical fatigue will be far more critical for those soldiers whose tasks may be physically demanding but which are also likely to be highly over-learned. The performance of such tasks is much more resistant to sleep loss than are tasks with higher order cognitive requirements.

The course of recovery from fatigue, or the amount of rest or sleep required to maintain desired levels of military effectiveness is also quite different for mental and physical fatigue. The opportunities for recuperative periods of rest required to reduce physical fatigue, and the rate at which that recovery occurs, can be greatly different from the opportunities

*In addition to mental fatigue and physical fatigue, there is a considerable literature on "combat fatigue". This usually refers to a maladaptive response to the stress of prolonged combat which requires a completely different recovery regimen than mental and physical fatigue. It is a clinical problem which was excluded from this review because it is a problem of personal adjustment rather than fatigue per se.

to fully restore the mental effectiveness of a high level decision maker who is severely sleep deprived. Considerable knowledge concerning recovery rates from mental and physical fatigue is now available for these problems to be effectively handled (circumstances permitting) by enlightened sleep management techniques.

Figure 1 depicts a conceptual framework representing the items of interest in the current study of fatigue effects on combat performance. The core set of items, in the central area of the exhibit, describe the human element. To the left and below these are items relevant to the battlefield conditions. System and performance areas are at the extreme right. Several classes of relationships among items are identified and correspond to the scope of variables currently accommodated in combat models, the scope of human stress and fatigue research, and the desired relationship among human and operational variables to adequately model the man-machine interface and human performance in combat models.

Human performance is a function of human traits and the individual's current psychological and physiological state. Human trait variables include:

- sleep requirements;
- physical fitness and maximum voluntary capacity;
- strength capability;
- psychomotor and perceptual abilities;
- cognitive abilities;
- initiative, self-discipline, and self-motivation; and
- anxiety proneness.

State variables enhance or attenuate performance through many mechanisms, including:

- physical fatigue or exhaustion;
- circadian pattern;
- hunger, thirst, or body temperature;
- motivation, vigilance, anxiety, or fear;
- training level or combat experience;
- uncertainty;
- confidence in leadership or discipline of unit; and
- coherence of the team.

Battlefield conditions occur outside the control of the human but impact the human's state, traits, and ultimately performance through stress. Among the various environmental, system characteristics, operational mode, and task conditions impacting human performance are:

- terrain;
- continuous operations;
- visibility, weather;
- noise, concussion;
- attrition (friendly or enemy);
- suppressive fire;
- ambush potential, mine fields, etc.;
- biological, chemical contaminants;
- enemy activity;

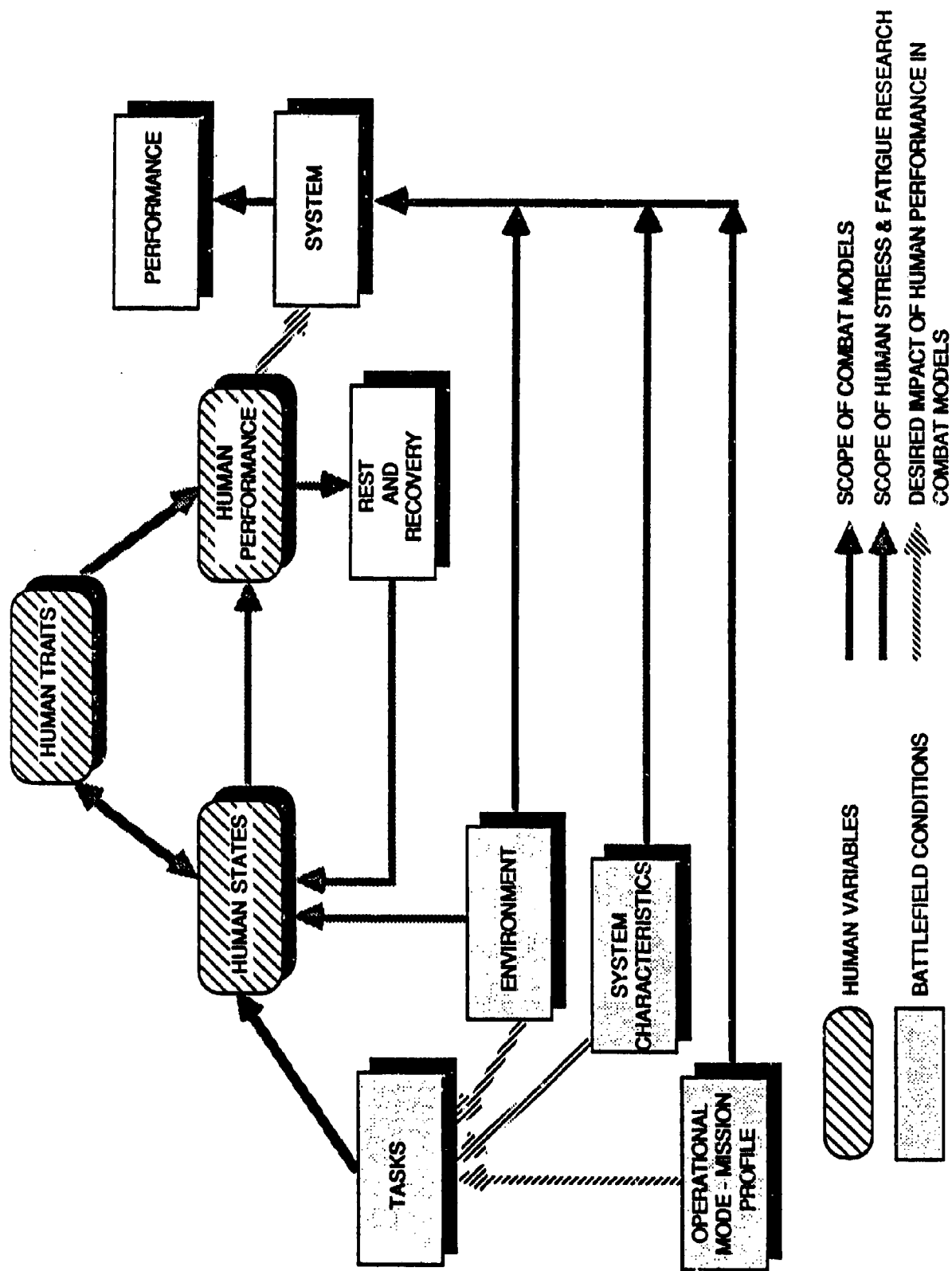


Figure 1. Framework of Variables and Relationships for Considering Human Variables in Combat Models

- weight of external load: and
- task frequency, duration or urgency.

Human performance is generally measured in terms of timeliness, accuracy, thoroughness, or quality, but is manifested through a range of task-specific behaviors which vary greatly in complexity and potential impact on combat effectiveness. These physical, psychomotor or cognitive activities include:

- sustained physical exertion as in rearm, refuel, resupply;
- vehicle control;
- construction;
- aiming and tracking;
- weapon/equipment operation;
- target acquisition, identification, and selection;
- leadership;
- command, control, and communications;
- planning; and
- calculating, coding, and intelligence gathering.

Traditionally, combat models have excluded the human factor in determining system performance during engagements. Instead, the characteristics and implications of system mission, operational, and environmental characteristics, have been emphasized. Assuming that human performance directly affects combat outcome and should be considered in these models, the key questions are: what data and quantitative relationships exist which would be of use to combat modelers, system developers, or combat analysts; and how can we relate that data to measures of system effectiveness.

This review considers both physical and mental fatigue. A considerable body of research exists in the area of mental stress resulting from continuous operations or sleep deprivation. Likewise, physiological stress resulting from high energy expenditure rates or severe muscular exertions, has been studied. Both areas of fatigue have been considered here in the context of individual performance.

A purpose of the literature search was to identify from available research both general and specific data regarding human performance in continuous operations. From this, we could identify the contributing factors in the stress and recovery process, particularly regarding fatigue. The ultimate goal is to improve our models of the combat processes through an improved understanding of human behavior as it is affected by physical and mental fatigue.

Document Users

Among the intended users of this document are combat analysts and modelers, system developers, combat developers, and MANPRINT training developers and personnel planners. The common thread uniting these readers is an interest in optimizing the combat process, and a sensitivity to the human component in that process.

Report Organization

These introductory remarks are meant to underscore the complexity of the problem of developing valid estimates of the effects of fatigue on the performance of military personnel. Any such modeling effort must recognize that there is no single function that can describe these effects in a military unit. It depends, first and foremost, on the nature of the tasks to be performed and whether or not they must be performed more or less continuously. It obviously depends also on opportunities for sleep and recuperative rest, and on the work schedules imposed. If that were not sufficient complexity, it also depends on a variety of modifying factors such as degree of training, unit leadership, weather conditions, requirements for use of protective clothing or being "buttoned up", and numerous other conditions associated with continuous and sustained operations.

Despite these complexities, much useful knowledge has been generated by research on how human behavior changes as a function of fatigue and related variables. The problems faced in developing quantifiable estimates of fatigue effects stem from the great diversity of experimental conditions employed in this research. In this review we have attempted to bring some order out of the chaos. While the results may not satisfy those who are looking for precise functional relationships, they do, we believe, reflect sufficiently reliable findings to justify the incorporation of some fatigue effects into combat models. Whatever the research deficiencies may be, it is in our opinion far better to take this information into account than to employ arbitrary values (including no values at all) in combat models.

The remaining sections of this research report present the approach for research study selection and the procedures for reviewing these selections, the results from the review of the mental and physical fatigue literature, and conclusions drawn and recommendations for further work. The document also includes three appendices which elaborate on specific studies, and present the full bibliography of references.

Specifically, Appendix A contains full synopses on 40 studies, selected for their relevance to the study's objectives. Appendix B contains abbreviated synopses of 72 studies which were of some relevance, but not as directly applicable as those in appendix A. Appendix C lists full citations on over 500 articles, reports, and books reviewed for this effort. For studies which were reviewed, but were not considered to be of sufficient relevance for inclusion in either appendix A or B, short annotations are provided based on the reviewers' comments.

APPROACH

This section documents the search, screening, and review strategies employed during the search of defense, government, and medical databases for reports relevant to fatigue, sleep loss, and human performance. The primary search concentrated on mental fatigue (with physical fatigue as a secondary issue). A second search concentrated on physical fatigue resulting from repetitive or prolonged exertions in a range of thermal environments. Procedures outlined below apply to both searches, unless otherwise noted.

Screening Procedure

The literature on fatigue and related stressors likely to be encountered in the battlefield is enormous, but much of it is not helpful from the viewpoint of performance problems posed by continuous operations. To constrain the literature search, which included the databases of the Defense Technical Information Center (DTIC), and the National Technical Information Service (NTIS), we employed a strategy that required report titles to include not only key terms such as fatigue and/or stress, but also performance. Special searches were also conducted on "human variables in combat", "combat fatigue", and "combat stress". These initial searches, plus a sizable reference list of our own on fatigue and other stressors, created a large inventory of potentially relevant articles and technical reports. Titles and abstracts were then thoroughly screened for apparent relevance to long term performance, loss of sleep, and other stressors likely to be encountered in a combat environment (e.g., heat, noise, vibration, enemy action). This search procedure was generally followed until the reference lists of newly acquired documents showed a high degree of overlap with those previously acquired.

Databases of DTIC and NTIS, as well as MedLine were searched for studies involving physical fatigue and related stressors. Relevant areas in this search included physiology, muscle strength, endurance, and rest and recovery periods. While reports of studies involving continuous operations and physical work from the military community were preferred, relevant industrial or laboratory studies involving repetitive manual materials handling, heavy physical work, physical work capacity, and heat stress were also considered.

Appendix C lists 500 articles, documents, and books that were received and examined as part of this process. The initial search identified 445 of these documents. Of these, 216 dealt directly with the impact of fatigue or sleep loss on some kind of human performance. Another group of 124 documents dealt with "related" stressors such as heat, noise, vibration, confinement, and fear associated with combat operations. Finally, 98 documents dealt more generally with background material useful for gaining an understanding of continuous military operations including descriptions of battles in wartime, training and leadership issues, war gaming, performance evaluation, and doctrine.

The second search for studies of physical fatigue provided 68 documents, all but 15 of which were new. General topic areas, and count of studies, uncovered in the second search include: sleep deprivation or

sustained operations (13); energy expenditure and physical work capacity (14); work pacing and physical fatigue (19); heat stress and heat acclimation studies (17); and strength capability during repetitive lifting (11). Some overlap in topic areas occurred among the documents; in addition, several of these articles were more background or review in nature. Of the 68 studies, over one-third (27) were performed by military laboratories.

Review Criteria

The scope of this project did not permit a detailed critical examination of all of these documents. Rather, the documents were prioritized for review according to the following criteria:

1. The study dealt with continuous or sustained operations explicitly.
2. The study contained data on the performance of a military task over a prolonged period, usually with some associated sleep loss.
3. The study contained data on performance of laboratory type experimental tasks over prolonged periods, usually with some associated sleep loss.
4. The study was a review article dealing with CONOPS, SUSOPS, or the general effects of sleep loss on performance.
5. The study purported to deal with extended periods of performance but contained no performance data.
6. The study dealt with fear stress in battle, or fear stress under simulated battle conditions.
7. The study was concerned with stressors other than fatigue or fear.
8. The study did not fall into any of the above categories.

All studies in categories 1-6 were given at least a minimal review. This means that the report was examined for details concerning the types of tasks performed (if any), the duration of performance, and whether or not objective performance data were reported. A summary judgment was then made about the degree of relevance of each article to continuous military operations. This judgment was made on the basis of experimental task similarity to military tasks, duration of the experimental procedure (i.e., amount of sleep loss), and similarity of the experimental environment to military environments. In all, 315 studies were reviewed, the majority of which were concerned with fatigue and sleep deprivation. A lesser number were concerned with fear stress and other battlefield stressors.

Those studies judged to have a high degree of relevance on each of the dimensions outlined above are reported in a common synoptic outline in appendix A. There were 40 such studies. Most are experimental and include meaningful task performance data; a few are comprehensive review studies.

A second group of moderately relevant studies (72 in all) are reported in appendix B. These studies were either less comprehensive than those in appendix A, or the experimental conditions were judged to be less directly relevant to military operations. Nevertheless, most were felt to provide information useful for this review.

The third group of studies were those judged to be of interest but not sufficiently relevant to warrant a detailed review. There were 190 of these in all. These are listed in appendix C (which also includes all studies in appendices A and B), along with notes by the reviewer concerning the experimental task, the types of stressors involved, and general observations concerning the findings or relevance of the study to present objectives. Many of these notes will be of interest to those doing research on the topics of fatigue and related stressors.

The reports in these appendices are listed within each appendix alphabetically by author. Citations for which synopses are available are noted in appendix C (full synopses in appendix A and abbreviated synopses in appendix B). Full bibliographic citations appear only in appendix C.

RESULTS FROM A REVIEW OF THE LITERATURE

Introduction

This section presents the results from the literature review of fatigue effects. Results are presented in two forms: an overview of the state of knowledge in the area (what we know, and what we don't know because of problems with the studies); and a presentation of the effects of sleep loss and fatigue for specific behaviors. The following section, "Conclusions", will present the results in yet another way: as a summary table of conditions and results of sleep loss studies organized by the duration of the experiment.

The reader should keep in mind that the focus has been on measures of performance and effectiveness resulting from fatigue at an individual man-machine level, rather than at the unit level.

General State of Knowledge

1. Much of the literature concerning the effects of fatigue on human performance, including studies where military type tasks were performed as well as those employing fundamental psychological tests, have been inconclusive (or misleading) because:

- The performance tests were too short and infrequently administered, and thus susceptible to short term mobilization of effort even by very tired subjects. This was true of some very comprehensive field studies (e.g., the Ainsworth and Bishop (1971) study of tank crews; the Haslam (1981, 1982, 1985) studies of infantry men and parachutists).
- In many studies the administration of the performance tests was temporally displaced from the main fatiguing and stressful events, also allowing for short term mobilization of effort or sometimes serving as a distraction from monotonous operations (e.g., Meeland, Egbert and Miller's (1957) study of Army basic trainees). Excellent examples of how the performance test should be embedded in the operational work session are provided by Angus and Heslegrave (1975); Mullaney, Kripke, and Fleck (1981); and Thorne, Genser, Sing, and Hegge (1983). These studies show systematically greater effects of fatigue than do those where testing is of short duration, or temporally isolated from main events.
- The performance tests used have often been of such a nature that learning effects were highly likely, thus confounding learning and fatigue effects and possibly obscuring important effects of fatigue on performance (e.g., Ainsworth and Bishop (1971); Englund, Ryman, Naithon, and Hodgdon (1985)).
- Linkage of the performance tests used to operational tasks was often unclear. The majority of studies incorporated tests of basic psychological phenomena although a significant minority incorporated reasonable simulations of military tasks (e.g., Meeland et al., (1957)). Similarly, limits of physical exertion determined on bicycle ergometers or laboratory treadmill are inap-

propriate for and considerably greater than actual work capacity for mixed static and dynamic tasks (load carrying, etc.) (Legg and Patton (1987)).

- Highly overlearned tasks were sometimes tested. These are known to be insensitive to fatigue effects (e.g., Ainsworth and Bishop (1971)).
- Relatively few studies have involved continuous work or complex tasks. When they do, decrements in performance are seen much earlier and may be severe after 36-48 hours without sleep (Belenky et al., (1986); Drucker, Cannon and Wear (1969); Angus and Heslagrave (1985); Mullaney, Kripke and Fleck (1981); and Thorne et al., (1983)).

2. There is little information on the combined effects of fatigue and other battle related stressors (e.g., heat, cold, vibration, confinement, noise). Levi (1972) incorporated recordings of "authentic battle noise" into his study of the effects of sleep loss on rifle shooting by Army personnel, and Rausch et al., (1986) have examined the impact of heat stress due to high ambient temperatures and the requirement to wear MOPP gear on howitzer personnel engaged in sustained operations. Randle and Legg (1985) verified that mixed static and dynamic work (e.g., carrying loads or handling artillery shells), conducted in hot conditions produced significantly more physiological strain and perceived exertion than purely dynamic work (e.g., treadmill walking). Conversely, Kilka, Martin and Elizondo (1984) found no difference in exercise work rates during exercise in cold environments (0 degrees C) after sleep deprivation. They concluded that the cold stress provided the motivation for the work.

Only two studies were found that addressed possibly the most important combination of all, fatigue and fear (Meeland, Egbert & Miller (1957); Bergstrom, Gillberg, and Arnberg (1973)). However, several studies have focused on personnel who were probably suffering from the combined effects of mental and physical fatigue (e.g., Englund, Naitoh, Ryman and Hodgdon (1983); Englund, Ryman, Naitoh and Hodgdon (1985); Bugge, Opstead, and Magnus (1979)). The most notable attempts to realistically stimulate the fear response remain those studies performed by Berkun and his associates (1959; 1964; 1962) who submitted Army basic trainees to evident aircraft emergencies, misdirected artillery shells, explosions, and radioactive fallout. Out of ethical considerations, studies of this type are no longer performed and it seems likely that Berkun's criteria for a valid study of effects of fear stress* will remain elusive as will any definitive statement concerning its possible interactive effect with fatigue.

3. Many studies do not report a baseline of performance, making it difficult to describe the effects of fatigue on performance in quantitative terms.

*Berkun's criteria include a cognitive response indicating the threat was accepted as genuine, a significant physiological stress response, and a negative affective response.

4. The adverse effects of sleep loss and fatigue impact performance on different types of tasks to very different degrees (Woodward and Nelson (1974); Johnson & Naitoh (1974)). Generally speaking, the literature rather clearly indicates that the most serious performance decrements are to be expected with cognitively demanding tasks, those requiring vigilance, and some tasks requiring psychomotor precision. Least affected are tasks that are highly over learned, including a variety of routine manual tasks. Englund et al., (1985) have shown that engaging in sustained physical work can delay the adverse effects of sleep loss to some extent on tests of cognitive performance, although others (e.g., Lubin (1975); Opstad (1978)) have claimed that physical fatigue makes the effects of sleep loss on the performance of cognitive tasks worse. Possibly, both viewpoints are correct depending on the amount of physical work. Legg and Patton (1987) demonstrated a significant loss in isometric hand grip strength values in artillery handling tasks as a result of prolonged partial sleep deprivation, and showed that recovery of muscular strength took longer than for non-sleep deprived trails.

Thorne et al., (1983) have shown that a wide variety of cognitive tasks are more or less equally affected by extensive sleep loss. There is some evidence that highly interesting tasks (such as games) are more resistant to sleep loss effects than monotonous ones; however, not even highly challenging, job relevant, militarily significant tasks escape the adverse effects of sleep loss for as long as 48 continuous hours (for example, see Banderet et al., (1980)). Belenky et al., (1986) regard cognitive abilities as the weak link in human performance during continuous operations.

5. Few studies have incorporated real world adverse environments and uncertainties, including the effects of darkness (night operations) on task performance. Notable exceptions include Banderet et al., (1980) and Ainsworth and Bishop (1971). Kopstein et al., (1979) include darkness as a variable affecting performance in continuous operations but do not provide any supporting data. However, circadian effects on performance have been widely studied (e.g., Bugge, Opstad and Magnus (1979); Dinges, Orne, and Orne (1985); Englund et al., (1985); Levi (1972); Rausch et al., (1986); and many others). It has generally been shown that there are pronounced circadian variations in performance on a variety of perceptual and cognitive tests, including tests of vigilance. In some cases these results have been shown to extend beyond laboratory type tests to meaningful, complex tasks closely associated with military operations. There is considerable experimental evidence supporting the "micro sleep" or "lapse hypothesis" during extended operations (e.g., Bugge, Opstad, and Magnus (1979)).

6. Performance feedback is rarely given in studies of fatigue and sleep loss although feedback is known to influence results and some have suggested that it will reduce the adverse effects of sleep loss considerably. Belenky et al., (1986) conclude that task performance is resistant to the effects of sleep loss when feedback is given but note that no amount of interest, motivation, or personal effort will be completely effective in counteracting the effects of sleep loss. Levi (1972) has clearly shown that regular performance feedback is not sufficient to overcome the effects of extended sleep loss on performance in rifle shooting.

Differential motivation between that which occurs during research studies and that which occurs when engaged in life threatening events is a

frequently raised issue in attempting to generalize from research results. This question is probably better answered by anecdotal material than research. Military personnel have frequently been observed to fall asleep on watch despite potential life threatening consequences. In several of the studies in this review, military personnel performing realistic tasks found it necessary to withdraw from the experiment after extended sleep loss despite presumably high incentive for continuing to perform (e.g., Banderet et al., (1980); Haslam (1981)). Wylie, Mackie and Smith (1985) have documented reports of military personnel falling asleep while engaged in flight operations during the Falklands war. Reports of soldiers falling asleep in the battlefield have been commonplace.

7. The results in much of the literature, can be expected to generalize to military personnel, both officer and enlisted. In 61 of the 89 (69%) experimental studies whose synopses appear in this report, military personnel were used as subjects. Their performance under fatiguing conditions has been measured on a diversity of military or simulated military tasks, as well as on more fundamental psychological tests of perceptual and cognitive functioning.

8. The literature gives strong evidence of operationally significant performance degradation after 36-48 hours, if work is more or less continuous. Some military personnel have been unable to continue simulated combat tasks after this amount of time (Banderet et al., (1980); Francesconi et al., (1978)). Performance on simulated tank crew tasks showed marked performance decrements after 48 hours without sleep (Haggard (1969)). Performance on vigilance rifle shooting has been shown to degrade during extended tactical exercises with serious impairment of performance after 48 hours (Haslam (1981)). Performance in a field artillery fire direction center deteriorated markedly in terms of speed of response and increased errors during 48 hours of continuous operations. Some tasks showed effects after as little as 18 hours without sleep (Banderet et al., (1980)). Other investigators who have reported significant adverse effects on military or simulated military tasks after 48 hours of wakefulness include Drucker, Cannon and Wear (1969); Angus and Heslegrave (1985); Mullaney, Kripke, and Fleck (1981); Morgan Jr. et al., (1973, 1974); and Thorne et al., (1983). Siegel et al., (1980) have claimed that there is "unanimity in the scientific literature that the full debilitating effects of sleep loss take place between the 36th and 48th hour of continuous wakefulness".

It should be noted that if an experiment on sleep deprivation is begun on the morning of the first day, as many of them have, then the period between the 36th and the 48th hours will also encompass the nadir of the circadian rhythm. Thus the effects of sleep loss and the lowest level in the cycle of psychophysiological arousal will be combined. It is at this point in time when some experimental subjects who have been required to perform more or less continuously have elected to withdraw from the experiment.

9. Self-paced hard work (i.e., physiologically stressful activity requiring hard energy expenditure such as marching with combat load over irregular terrain) has been studied over a range of durations, terrains, and loads (Evans et al., (1980); Hughes and Goldman (1970); Levine et al., (1982); Myles et al., (1979); Soule and Goldman (1973 and 1978)). The level of energy expenditure which soldiers will achieve to maintain the work varies

with the duration of exertion, from 45 percent of maximum energy expenditure (VO_2 max) for 2 hour marches to 30 percent for 6.5 hour marches. These ratios are consistent for both males and females.

10. Only a few relevant studies of fatigue due to repeated muscular exertions have been performed by military agencies. An exception is Legg and Pateman (1984), who found that the expected energy expenditure level should be reduced significantly for repetitive lifting tasks (to 23 percent of VO_2 max). Many more studies exist in the industrial and academic literature (most notably the NIOSH guidelines for manual lifting, (NIOSH 1981)). Application of industrial data to military scenarios is appropriate only if the task conditions (load, frequency, posture) and operator physical traits are compatible (e.g., similar training, fitness, and strength capabilities).

Effects of Fatigue and Sleep Loss in Specific Functions

There has been considerable commonality in the types of experimental tasks employed in research on fatigue and sleep loss. For this reason it is possible to reach some generalizations concerning such functions as vigilance, reaction time, the higher cognitive functions (perception, cognition, memory, reading comprehension); tracking and psychomotor performance; and physical work.

Vigilance. Vigilance or the ability to sustain high levels of attention during the performance of routine or monotonous but very important tasks has frequently been studied in the context of fatigue and sleep loss. One night's sleep loss has been shown to adversely affect auditory vigilance (Glennville et al., 1978) and performance on visual vigilance tasks (Wilkinson, 1960). Other investigators who have found marked performance degradations in vigilance after sleep loss include Angus and Heslegrave (1985); Mullaney, Kripke, and Fleck (1981); Opstad et al., (1978); Thorne et al., (1983); and Frazier et al., (1971). It is believed (Woodward and Nelson (1974)) that as sleep loss progresses, brief intermittent lapses in perceptual performance increase in both frequency and duration. It has also been shown (Norton (1970)) that sleep deprivation plays an important role in ability to maintain selective attention, where subjects are required to discriminate between relevant and irrelevant information.

Reaction Time and the Speed-Accuracy Tradeoff. Reaction time to a variety of simple stimulus conditions is also a widely studied phenomenon in the literature on fatigue and sleep loss. The adverse impact of sleep loss on reaction time has been shown by Angus and Heslegrave (1985); Englund et al., (1983, 1985); Opstad et al., (1978); Thorne et al., (1983); Perelli (1980); Dinges (1985); Naitoh (1983); Naitoh & Townsend (1970); and Edwards (1941). One of the more interesting and possibly operationally significant studies of reaction time involved the task of vigilance rifle shooting employed by Haslam (1981, 1982, 1985) in which a requirement for rapid detection of a target was combined with that of accurate shooting of the rifle at that target. Significant degradation was observed as a function of sleep loss despite test periods of relatively short duration.

Many military tasks do not require instantaneous response although there is considerable pressure to perform many tasks as rapidly and as

accurately as possible. The literature on sleep loss and fatigue effects is particularly interesting in this regard in that a number of studies have shown that when task performance is under control of the subject (at least to a reasonable degree) the fatigued subject will sacrifice speed for accuracy. Angus and Heslegrave (1985) observed increased message processing time during a simulated command and control task; Banderet et al., (1980) in studying the performance of field artillery fire direction center personnel found that the accuracy of work suffered and errors of omission increased with sleep loss, but that these errors were corrected before responses to calls for artillery fires were made. Thus, increasingly more time was required to perform the tasks satisfactorily and an increasing amount of required work never got done. Thorne et al., (1983) noted a similar effect with respect to a number of tests measuring various aspects of cognitive functioning thought to be important in command and control. As the effects of sleep deprivation increased, subjects required more and more time to accomplish the same series of tasks. There was a moderate and continuous reduction in accuracy and a much increased reaction time for all subjects on all tasks in the performance battery. Myles and Rommet noted increased times taken for combat engineers to complete their tasks as a function of sleep deprivation; Rausch et al., (1986) observed large increases in the time taken to accomplish artillery tasks, and Shine (1957), studying a simulated communication task, noted a marked increase in the number of errors made that had to be corrected, with a consequent increase in performance time as a function of increased sleep loss.

It is of interest that in several of these studies increased performance time was a consequence of realization by the subjects that they were more prone to making errors so that more double checking was necessary, and more corrections had to be made before the results of their performance could be transmitted to others who are depending on them. Thus an expected consequence of sleep loss and fatigue is a reduction in throughput. Thorne et al., (1983) have shown how a measure of throughput can be used to conveniently compare the impact of fatigue on the performance of a wide variety of cognitive tasks.

Cognitive Processes. The literature rather consistently indicates that tasks involving high level cognitive functions (memory, reasoning, arithmetic computations, concept attainment, communications, decision making) are adversely affected by fatigue and sleep loss. Like vigilance, cognitive behavior appears to be affected earlier and more severely than tasks involving primarily motor skills and muscular activity. Woodworth and Nelson (1974) in their summary of the literature reported that the types of impairment most likely from sleep loss include failure of short term memory, reduced speed of learning, impairment in reasoning and complex decision chains, and performance that is generally marked by increased variability in proficiency. Belenky et al., (1986) conclude that the more cognitively demanding a task, the greater is its sensitivity to sleep loss, and note that no amount of interest, motivation, or personal effort of any kind will be completely effective in counteracting the effects of sleep loss. Citing studies which indicate that soldiers become militarily ineffective after 48-72 hours without sleep, Belenky et al., feel that this will be particularly true of those with command and control responsibilities. They feel that cognitive abilities are the weakest link in the chain of human performance in sustained operations.

Angus and Heslegrave (1985) who studied the effects of sleep loss on cognitive performance during a simulated command and control task found that measures of logical reasoning declined to 72% of baseline during the first night without sleep and to 41% during the second night. Message processing times and time required to answer questions contained in messages were significantly poorer on the second day than the first and showed the steepest performance degradation during the night between days 2 and 3.

Performance in encoding and decoding of messages and map displays has been studied by several investigators including Haslam (1982) and Opstad et al., (1978). Haslam found that extensively sleep deprived groups had performance scores ranging from 28% to 35% of baseline after 6 consecutive days of operations. Computational performance similarly declined. Opstad et al., (1978) found significant impairment on a coding test after only 24 hours without sleep.

Several investigators have observed adverse effects of sleep loss on memory functions. Williams et al., (1966) showed that one night's sleep loss adversely affects tasks requiring memory for words. Belenky et al., (1986) report that tasks that require short term memory utilization are sensitive to sleep loss. Woodworth and Nelson (1974) also report a short term memory decrement and, a possibly related phenomenon, impairment in speed of learning. Mullaney, Kripke, and Fleck (1981) observed performance degradation on a visual pattern memory test, and found significant deterioration within the first 24 hours, contrary to many other sleep loss experiments, in a situation where continuous attention-demanding work had to be performed. The same investigators found significant degradations in numerical addition skills within the first 24 hours. In general their subjects had marked difficulty in continuously performing cognitive tasks for as long as 42 hours.

Thorne et al., (1983) employed measures of memory, logical reasoning, pattern recognition, and decision making over a period of 72 hours of continuous performance and enforced wakefulness. Performance on these tests was measured with a common metric, called "throughput", which enabled performance on diverse tasks to be compared in terms of the number of correct responses divided by cumulative reaction time for each of the tests. The average throughput declined 74% from baseline over the 72 hour period, and Thorne and his colleagues concluded that overall throughput dropped approximately 1% per hour or 24% per day compared to baseline. Of considerable interest was the finding that the pattern of decline in throughput was very similar for each of several different cognitive tasks.

Perelli (1980) developed a measure of information processing based on a 5-choice adaptive reaction time task. Flight personnel on 12 hour duty days for 4 consecutive days, 9 hours of which was spent in a flight simulator, showed an increased threshold for information processing due to fatigue even though all of the subjects had an opportunity for a reasonable amount of sleep (greater than continuous operations would likely permit).

Finally, Kopstein et al., (1985) report the following generalizations about the effects of prolonged continuous operations on the performance of soldiers in mechanized infantry, armor, FIST, and artillery operations: decreased vigilance, reduced attention, slowed perception, inability to concentrate, faulty memory, slowed comprehension, slowed responding,

increased omissions of tasks, encoding/decoding difficulties, fuzzy reasoning, and communication difficulties. Specific citations for these effects are not given although there is nothing in this list that is contradicted by the current review.

Tracking and Psychomotor Performance. Tasks requiring smooth tracking and skilled psychomotor performance appear to suffer significant performance deterioration as a result of sleep loss beginning within the first 24 hours. However, highly over learned motor tasks are less susceptible to fatigue effects. Buck (1975) found that tracking performance (movement time) was adversely affected by 1 or 2 nights without sleep. Hockey (1970) showed that one night's sleep loss reduces attention allocation and pursuit tracking accuracy. Ellingstad and Helmatra (1970) showed that complex psychomotor performance deteriorated substantially after only 15 hours of continuous work. Tracking performance deteriorated as reflected both in the amount of time off the target track, and the number of times off target, over the 15 hour continuous work session. The tracking task in this case was similar to that required in automobile steering. Orr (1964), studying subjects in an aircrew simulator for 21 continuous hours, found progressive deterioration in directional control and complex coordination. These subjects showed a marked drop in performance on a concurrent vigilance task after only 10 hours in the simulator. Mullaney, Kripke, and Fleck (1981) employed a tracking task that required the subjects to use a joy stick to position a target to the exact center of a grid and then press a trigger in an effort to score a hit. This task was mixed with others that were performed on a continuous basis. It was found that performance deteriorated seriously even within the first 24 hours. Finally, Haslam (1981, 1982, 1985) has consistently found that fatigue and sleep deprivation have adverse impacts on vigilance rifle shooting. Performance when no sleep was allowed for up to 90 hours was 25% below that achieved when 4 hours of sleep per 24 was allowed. In the 1985 study 62% of the targets were hit on baseline and recovery days but only 25.6% on the 6th trial day. Grouping capacity also was significantly worse on the 4th, 5th, and 6th day of sleep deprivation. These values are probably quite conservative since the vigilance rifle shooting task was performed for only 20 minutes, once per day. Levi (1972) also studied rifle shooting for speed and accuracy and found that both the number of shots per hour and the number of hits decreased throughout a 72 hour period without sleep. In addition, there were notable circadian depressions in both performance measures.

Physical Work. There are three relevant issues in the research literature concerning extended periods of physical work: (1) the maximum working capacity to maintain performance and resist fatigue; (2) the adverse effects of physical fatigue per se on the ability to continue effective performance; and (3) the possibly beneficial or adverse effects of physical activity on other aspects of performance requiring, for example, vigilance or various cognitive skills.

Within the first issue, the maximum work rate sustainable for prolonged activity expressed as a percentage of maximum aerobic power (VO_2 max), and the psychophysics of perceived exertions (Snook and Irvine (1968)) are indicators of performance.

When comparing studies of increasing duration of work (2 to 6 hrs per day, up to 6 days duration), the relative energy expenditures (as a percent of VO_2 max) decreased with increasing duration (from 45 percent to 36 percent, noted in Levine et al., (1982), and from 40 percent to 32 percent in a study by Myles et al., (1979)). Once established, the level of work remains relatively constant over different terrains and across genders (Evans et al., (1980)). Carrying loads of more than 40 to 50 percent of body weight (Hughes and Goldman (1970); and Pierrynowski et al., (1981)), carrying loads in unbalanced positions (Soule et al., 1978a), or working under increasing thermal load, limit the percent of VO_2 max required to maintain acceptable performance and eliminate heat exhaustion. Similarly, the level of training tends to increase work efficiency, with the trained subjects able to perform the same work at roughly 35 percent of VO_2 max, as untrained subjects working at the higher relative cost of 44 percent (Levine et al., (1982)). Many of these results have been incorporated into a model of metabolic cost of load carrying under varying terrain, grade, and march rates (see Pandolf, Givoni, and Goldman (1977); and Wagner and Kunz (1986)).

Mixing static activity, such as standing, or holding materials in front of the body, with dynamic activity, tends to increase the workload in normal, dry environments (see Legg and Pateman (1984)), as well as in hot, dry conditions (Kamon and Belding (1971); and Randle and Legg (1985)). With materials handling, the lift frequency (lifts per minute) dictates whether performance will be limited by muscle strength (for frequency less than 3 lifts per minute) or aerobic capacity (Khalil et al., (1985)).

The psychophysical approach to lifting, or the perceived exertion, contrasts "what man can do" with "what man will do" (Snook and Irvine (1968)). In many cases, physiological measures, such as heart rate or energy expenditure, show no change between two levels of thermal load, grade, or sleep deprivation, but subjects will report increased levels of perceived exertion, leading to significant decrements in exercise tolerance (see Martin, 1981; Soule and Goldman (1973); and Rayman, Naithoh, and Englund (1987)).

Regarding the second issue for physical work, Myles and Rommet (1986) have shown that where sleep deprivation of up to 69 hours is combined with a requirement for heavy manual work up to 48 hours, the self-paced effort of combat engineers begins to decline after only 14 hours of work. On the other hand, Belenky et al., (1986) claim that tasks which require primarily physical performance are relatively immune to the effects of sleep loss. Bugge et al., (1979) conclude that the combined effects of sleep loss and physical exhaustion may potentiate the fluctuations in the natural circadian rhythm. If this is true, the effects of physical exhaustion could influence other types of concurrent tasks that involve the cognitive domain. These investigators have shown that performance on various cognitive tests including logical reasoning, perceptual speed, speed of association, as well as measures of motor coordination, showed significant and substantial impairment during continuous military field operations (a Ranger course). With sleep limited to 1-2 hours per 24, the lowest level of performance occurred on the 4th day with a reduction to 50-60% of baseline values. In addition, the effects of circadian variation were much more pronounced during field operations than they were during a control

period. Circadian variations in logical reasoning were plus or minus 40% of baseline during field operations compared to a normal variation on baseline days of plus or minus 10% of the 24 hour mean. These effects occurred despite tests of extremely short duration which, however, were administered several times during each 24 hour period.

Regarding the third issue, it has been shown that physical fatigue resulting from extended marches on a treadmill (11 Km) in full combat gear affects various psychological functions (vigilance, reaction time, reasoning, reading) less than sleep loss or circadian effects (Englund et al., (1983)). However, Opstad et al., (1978) have reported that heavy physical work, combined with little sleep over 4-5 days produces decrements in vigilance, reaction time, shooting performance, and performance on a command memory task. Some of these effects are evident as early as 24 hours without sleep. Similarly, Lubin et al., (1975) report that physical exercise during 40 hours without sleep can increase impairment of auditory vigilance, word memory, mathematical performance, and digit span.

Bonnet (1980) studied the effects of marching for 20 miles (6.5 hours) on vigilance, numerical computation, choice reaction time, short term memory, and symbol substitution. He reported significant decrements on each of these tests at the end of the march which approximated those reported in the literature following 40 hours of sleep deprivation. Finally, Englund et al., (1985) studied the combined effect of physical work and sleep loss (6 hour marches and 48 hours of continuous work) and concluded that subjects who marched, as opposed to those who engaged in sedentary activity for a similar period of time, showed a delay of as much as 8 hours in degraded performance on a visual vigilance task. They concluded that moderate exercise does not combine with sleep loss to further decrease cognitive performance.

The Recovery Function. A number of investigators, but by no means all, have attempted to describe not only the amount of performance degradation as a function of fatigue and sleep loss, but the amount of sleep in the form of naps or more extended recovery periods, necessary for performance to fully recover to baseline levels. A number of studies have shown that personnel who were given the opportunity to sleep for 3-4 hours in every 24, can sustain performance at various tasks for several days. It would be easy to be misled by this kind of result, however, unless it is recognized that opportunity will have to be provided at a later time for full recovery from the cumulative sleep deficit. Haslam (1982) showed, for example, that after sleep deprivation for 90 hours, 4 hours of block sleep had a beneficial effect upon some aspects of soldier's performance, e.g., vigilance rifle shooting. The same amount of sleep however was not sufficient for recovery to control levels on tests of reasoning, and was not sufficient for recovery on a decoding test when that test was given at low points in the circadian cycle. Indeed, 3 days of rest, with an average of 19 1/2 hours spent asleep, were necessary to eliminate all remaining performance decrements.

Opstad et al., (1978) showed that both 3 and 6 hours of sleep during an extended 4-5 day Ranger training course had beneficial effects on various cognitive functions as well as rifle shooting, but the time required for full recovery was not established. It was noted that even 24

hours after the end of the course, performance on a vigilance test, reaction time test, and coding test had not recovered to baseline levels.

Englund et al., (1983) found that one 3-hour nap between two successive 20-hour periods of sustained operations had no immediate beneficial effect on the performance of cognitive tasks during the second extended period of continuous work. Naith, Englund, and Ryman (1983) studied two 20-hour periods of continuous work with either 0, 3, or 8 hours of sleep in between the two periods. It was found that the 3-hour nap which was taken at the low point in the circadian cycle was restorative of performance on some cognitive tasks but not others. These authors suggested a sleep logistics model for the prediction of performance during continuous work periods. The model includes 3 parameters: (1) duration of the continuous work period; (2) duration of the nap; and (3) time of day when the nap is taken.

Mullaney, Kripke, and Fleck (1981) contrasted 6 hours of continuous sleep during a 42 hour work schedule with 6 1-hour rest periods equally spaced throughout the 42 hour performance period. Totally sleep deprived subjects performed more poorly on all tests than did those who received 6 hours of sleep. In general, 6 hours of block sleep resulted in better performance than did 6 1-hour naps. Subjects permitted 6 1-hour naps experienced a sleep "hangover" when engaged in their first performance test following the sleep period. This phenomenon, also called "sleep inertia", has been shown to have an adverse effect on cognitive performance for several minutes following awakening.

Myles and Romat (1986) in studying the performance of combat engineers concluded that 4 hours of dedicated sleep every night was not sufficient during sustained operations if the 20 waking hours had been spent in prolonged, fatiguing tasks. Even though such personnel might continue to perform, self paced work output can be expected to decline. Morgan et al., (1973) reported that following 36 hours of continuous work, 2, 3, and 4 hours of sleep yielded recoveries in performance of 76 percent, 56 percent and 75 percent respectively, whereas 4 hours sleep following 44 hours of continuous work produced only 39 percent immediate recovery on a multiple task performance battery. They suggested that 6-8 hours is the minimum amount of sleep required for recovery of performance from the effects of 36 hours of continuous work and sleep loss. Dinges, Orne, and Orne (1985) studied the effectiveness of a 2-hour nap following various amounts of sleep deprivation (6, 18, 30, 42, or 54 hours). They noted that sleep deprivation increases the amount of deep sleep in naps and this is associated with greater post-nap cognitive performance decrements. They felt in particular that 2-hour naps taken in the circadian trough probably should be avoided, a counter intuitive conclusion.

Woodward and Nelson (1974), following their review of the literature, concluded that the time required for recovery and adjustment after varying amounts of sleep deprivation was as follows:

- After 36-48 hours of acute sleep loss, 12 hours of sleep/rest is required and subjective fatigue may linger for 3 days;
- After 36-48 hours sleep loss with a high work load (12-16 hours per day) 24 hours of sleep/rest is required;

- After 72 hours or more of acute sleep loss, 2-3 days of time off is required.

Belenky et al., (1986) drew the following conclusions:

- There are wide individual differences in the amount of sleep required each night, ranging from as little as 3.5 hours to as much as 10-12 hours. The vast majority of adults require 6-8 hours of sleep each night to maintain adequate, normal levels of daytime arousal.
- Chronic restriction of sleep length to less than 4.5 hours each night is not possible. This is the lower limit of sleep length plasticity for most individuals and failure to obtain at least 4 to 4 1/2 hours sleep each night results in rapid deterioration in performance on even the simplest of tasks.
- Even on restricted sleep schedules which allow more than 4.5 hours of sleep per night, there is a cumulative sleep debt reflected by increasing daytime sleepiness. This may be tolerated for several days or even weeks, but the sleep debt is never fully satisfied until recovery sleep is obtained.
- Partial sleep deprivation diminishes reserves for coping with a subsequent sustained operation.
- In maneuver warfare there are definable limits which if exceeded result in reaching the point of diminishing returns in performance effectiveness, with a potential for catastrophic failure. For sustained operations, the limits are 2-3 days.
- Cognitive abilities are the weak link in human performance in continuous operations. 6-8 hours of sleep each night will maintain cognitive performance indefinitely. 3-4 hours will maintain cognitive performance for 5-6 days. Less than 3 hours each night will lead to rapid declines in cognitive performance and military effectiveness.

The literature would generally seem to endorse these conclusions. However, it has been clearly shown that some aspects of cognitive performance cannot be maintained for 5-6 days with a sleep limitation of 3-4 hours per night. Much depends on the task and the extent to which the workload is continuous. Also, we have cited numerous examples in this review where critical military tasks suffer extensive performance decrements prior to a full 48-hours of continuous work effort.

Other Literature Reviews

Other authors have undertaken reviews of the literature related to this one. These review articles were Johnson and Naitch (1974); Harris and O'Hanlon (1972); Michel and Solic (1983); and Belenky et al., (1986). These reviewers range widely in their optimism concerning the usefulness of

the information in the research literature with respect to application. Johnson and Naithoh were perhaps the most pessimistic, stating,

Within the 36-48 hour range of total sleep loss most likely to be experienced by air crew personnel, no consistent or uniform performance decrement has been found in operational studies even though laboratory studies have found decrement on certain types of tasks. Of major importance are the type of task, the setting in which the task is to be performed, and the individual. Physiological changes are minimal during moderate sleep loss, but mood changes are clearly noticeable.

The most likely sleep problems for air crew members are those associated with disruption of sleep-wakefulness cycles and partial sleep loss. Consistent performance decrement is difficult to find, but marked increase in fatigue is a common problem. Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses. (Page 1).

And later they state,

What are the operational consequences of sleep loss and sleep deficit? Short of prolonged sleep loss of greater than 60-72 hours, it is difficult to categorically state what the effects of sleep loss on performance will be. Whether a performance decrement will occur during sleep loss depends on a complex interaction of the task, situational and personal factors. The nature of the task in its meaning to the subject, particularly its survival value, are of primary importance in the type of sleep deprivation effects which occur. (Page 33).

In contrast to this rather pessimistic outlook, the "user oriented review" of the literature by Woodward and Nelson (1974) provides specific statements concerning types of tasks most vulnerable to sleep loss effects; work schedules most vulnerable to performance impairment; amount of sleep loss required to impair performance; types of performance impairment most likely from sleep loss; procedures for reducing performance impairment risks in continuous operations; and time required for recovery and adjustment from unusual work schedules.

Belenky et al., (1986) similarly arrive at a large number of relatively specific conclusions concerning relationships which they regard as well established between sleep loss and performance decrements on various cognitive tasks. These include the correlation between the length of task and its sensitivity to sleep loss; the differences in sensitivity to sleep loss of subject-paced versus externally-paced tasks; the beneficial effect of performance feedback in maintaining performance under sleep loss; likelihood that soldiers will become militarily ineffective after 48-72 hours

without sleep; the fact that cognitive abilities are the weakest link in the human chain of performance in sustained operations; the expected decline in continuous work performance if there is no sleep during a 24 hour period; the adverse effects of chronic restriction in sleep length over periods of several days, and the related problem of cumulative sleep debt; the problem of sleep inertia associated with short periods of sleep (naps); and the probable limits of sleep deprivation before a catastrophic failure of performance is the result.

Finally, Harris and O'Hanlon (1972) in the earliest review of the literature directly concerned with sustained and continuous operations focused their attention on the recovery function. They concluded that there had been no directly relevant studies of continuous operations where men had performed operational tasks under field conditions on given work/rest and performance/recovery schedules for extended periods of time. In their view the literature at that time did not provide the data necessary to implement the continuous operations concept, but it did provide guidelines for the design of studies to collect the required data. Harris and O'Hanlon emphasized that one cannot generalize from performance in laboratory tasks to performance on real military tasks which are often complex and highly learned. Complex tasks are more likely, they say, to be sensitive to the effects of adverse conditions; well learned tasks more likely to be resistant. The military tasks most likely to suffer performance decrements under adverse conditions are monitoring tasks (vigilance), perceptual tasks that require interpretation of events and appropriate responses, and complex decision tasks that call on short term memory.

Harris and O'Hanlon also emphasized the importance of experimentation under field conditions. Laboratory conditions in which some significant variables are present, like sleep deprivation, and many others are absent, like environmental stressors, provide little basis for determining the effects of adverse conditions on performance or on physiological responses. Some combination of stressors is undoubtedly always present in the field. One important field stressor in the military situation is the amount of physical work done by soldiers in marching, carrying loads, fighting, and so on. The effects of this stressor, together with those of environmental stressors, will certainly interact to determine the capability of men to endure particular work/rest and performance/recovery schedules, and the course of recovery will certainly depend on the nature and intensity of the field stressors.

Harris and O'Hanlon underscore the importance of likely cumulative effects where the rest periods are not adequate to fully restore all functions. No one knows, they say, if it is necessary to completely return all physiological systems to a normal range of functioning before again exposing men to adverse conditions. But if systems are not adequately restored, the consequences may be a sudden failure in a system that could immobilize a soldier. The important questions to be answered concern the effects of repeated exposure periods on performance and physiological status. Does the cost of maintaining effective performance build to a breaking point? And what recovery schedules are necessary to prevent accumulation of these effects?

It is our conclusion that a great deal has been learned since the earlier reviews of Johnson and Naith, and Harris and O'Hanlon. Recent

researchers, though not all, have employed more sophisticated task and performance measurement techniques. It is our view that we now know enough to make a beginning on the modeling problem, even though we do not know as much as we would like.

CONCLUSIONS

The purpose of this section is to summarize the findings thus far, and to set a course for further research needed to model human performance in combat models. We do not feel that it is possible, at this time, to develop an equation to predict soldier fatigue from the range of variables addressed in the research reviewed to date. What we have done, however, is to construct a summary table of the research results, organized along the duration of sleep deprivation.

The summary table is as close as we can come to a functional relationship between fatigue and performance, particularly regarding cognitive, psychomotor, and perceptual tasks. Variations in subject tasks and experimental conditions make it difficult to fit one specific fatigue equation to the data. Prediction equations for physical activity may be more feasible, although attempts to date have been one level away from predicting time to exhaustion or failure. For the most part they identify the level of stress and leave it to the analyst to identify the point in time when failure occurs. These and other issues are discussed in this final section.

State of Knowledge

Experiment Summary Table. At the outset of this report we mentioned the great diversity of experimental designs and performance tasks that characterize the research literature on fatigue, sleep loss, and other stressors. This makes generalizations of results that might serve model building particularly difficult. One common dimension along which all the studies can be ordered, however, is time. Since we view time-dependent results as critical to modelling human variables in combat, in the table on the following pages we have summarized a substantial number of the studies reviewed in this project, listed in order of the duration of each experiment. Hopefully, this will be useful in identifying regularities in the results and the reasons for some of the differences.

The entries in the first column of the table give the duration of the experimental period, the amount of sleep allowed (if any), and the number and type of experimental subjects employed. The second column, "Primary Tasks", describes the tasks that occupied the subjects most of the time. The "Probe Tasks", summarized in column 3, are the tasks used by the experimenters to quantify human performance during the experiment. Probe task schedule information is given in the fourth column. The results of each experiment are summarized in column 5, and reference citations are given in the last column.

Prediction of Physical Fatigue. The Soldier Load Assessment (SLA) methodology, prepared for the Army Research Institute by Dynamics Research Corporation (Wagner and Kunz (1986)), utilizes the research and the model developed by Pandolf, Givoni, and Goldman (1977) at the US Army Research Institute for Environmental Medicine at Natick, Massachusetts, to identify the metabolic cost of load carrying. This model, as implemented in Wagner and Kunz, is described in the synopsis in appendix A, and is not reproduced here.

Table 1. Experiment Summary Table, Page 1 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
8 hrs duration, 0 hrs sleep, 64 USAF scaries in U.S., 96 in S.E. Asia.	Nighttime 8-hr sentry duty hours (same in U.S. and same in Southeast Asia in a combat environment).	Detection of randomly illuminated lights. Lights were placed in a quadrant c. 50 ft. from the airplane or missile being guarded. Subjective reports of fatigue were also taken.	Lights were lit at random intervals, mean time between signals = 15 min.	In U.S. sentries had increasing feelings of fatigue with time on watch but no change in light detection time, while S.E. Asia sentries showed increasing fatigue and increasing detection times.	Sanford, et al. 1971.
15 hrs duration, 0 hrs sleep, 15 men.	Tracking (like seeing a car).	Perceptual motor, memory, cognitive, vigilance.	Continuous, 15 hours.	Tracking degraded, other tasks not.	Ellingsrud & Helms, 1970.
21 hrs duration, 0 hrs sleep, 2 AFBOTC students.	Continuous performance in aircrew simulator.	Perceptual motor, cognitive, vigilance.	Continuous, 21 hours.	Major decrements for most tasks. Sleep vigilance drop off after 10 hrs.	Orr, 1964.
24 hrs duration, 0 hrs sleep, 15 sailors.	Wakefulness, not otherwise specified.	Vigilance.	40 minutes at end of experimental.	Degradation after first 20 min, compared to control group.	Wilkinson, 1960.
24 hrs duration, 0 hrs sleep, 12 sailors.	Wakefulness, not otherwise specified.	Simultaneous perceptual-motor (pursuit tracking) and vigilance.	Probe tasks at end.	Task performance was impaired.	Hockey, 1971.
24 hrs duration, 0 hrs sleep, 8 men.	Wakefulness, not otherwise specified.	Perceptual-motor, memory, reaction time, vigilance.	Brief probe tasks at end.	Reaction time and vigilance impaired, short- term memory and handwriting not.	Glensville, et al. 1978.
24 hrs duration, 0 hrs sleep, 36 artillery men.	155 mm howitzer live- fire exercises.	(Measured performance of primary tasks)	Continuous.	Performance and subjective state degraded between 0100 and 0700 hours.	Rausch, et al. 1986.
30 hrs duration, 0 sleep allowed (or normal sleep), up to 16 sailors per probe task.	Wakefulness through the night (talking, writing, playing cards, table tennis).	Sorting cards, forward & backward writing, rote learning, vigilance, serial reaction time, addition of numbers.	Each subject was required to perform one probe task (lasting 10 to 40 minutes) after a night without sleep (or normal sleep, for control S's).	No decline in efficiency was found following sleep loss in performing tasks lasting less than 10 minutes. Decline after 10 minutes was found in the serial reaction time test (25 min) and vigilance (40 min) but not the addition task (25 min long). Performance feedback reduced the sleep loss effects.	Wilkinson, 1938.

Table 1. Experiment Summary Table, Page 2 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
36 hrs duration, 0 hrs sleep, 44 soldiers.	Wakefulness, not otherwise specified.	Memory (word list recall, face recognition).	Probe at beginning and end.	Impaired recall of word list, picture recognition unaffected.	Williams, et al. 1976.
48 hrs duration, 3.7 hrs sleep per 24, 40 young men.	Exercise, rest, or napping.	Addition, word memory, digit span, vigilance.	Alternating 60-min "treatment" & 160-min "testing" for 40 hrs. Three treatments were used: 10 S's exercised, 20 S's rested (awake), 10 S's napped.	All groups showed decrements. The "nap" group was least affected, the "exercise" group most affected.	Lubin, et al. 1976.
42 hrs duration, 0 or 6 hrs sleep, 32 men.	Target tracking, visual memory, addition, vigilance.	(Measured performance on primary tasks)	Almost continuous (very important).	Performance on all tasks deteriorated within 24 hrs. Subjects permitted 6 1-hr naps hrs affected; those with 6-hr block of sleep least affected.	Mallory, et al. 1951.
44 hrs duration, 0-4 hrs sleep, 12 young men.	"Multiple-task performance battery" (perceptual-motor, cognitive, memory vigilance).	Same as primary.	36 hrs continuous work followed by 2-4 hrs sleep, or 44 hrs continuous work.	36 hr period had 14-18% performance efficiency decrements; 44 hr period had 22%. 2-4 hrs sleep after 36 hrs work brought c. 60% recovery, whereas 4 hrs sleep after 44 hrs work brought only 30% recovery. Authors suggest 6-8 hrs are needed for full recovery after 36 hrs continuous work.	Morgan, et al. 1973.
45 hrs duration, 3 hrs sleep, 22 marines.	Waiting on train, drill with full combat gear at 31% max VO2 metabolic.	Rifle disassembly/reassembly, simulated AAW, simple reaction time, psychomotor test, 4-choice serial reaction time, reasoning, memory, vigilance.	Two 20-hr continuous work episodes separated by 5 hours, including sleep from 0400 to 0700.	Performance was degraded (9% - 55%) in the second work period. This was judged to be caused by sleep loss and circadian effects, not physical workload.	Englund, et al. 1955.
48 hrs duration, 0, 3, or 8 hrs sleep, 22 marines.	Physical work at 30-40% max ability.	Reaction time, reasoning, reading, memory, vigilance.	Two 20-hr periods of continuous work with 0, 3, or 8 hrs of sleep in between.	Physical work did not worsen or improve performance decrement caused by sleep deprivation alone. When no sleep was allowed, all tasks were degraded. A 3-hour nap restored performance on some tasks. A math model was developed.	Naitoh, et al. 1983.

Table 1. Experiment Summary Table, Page 3 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
48 hrs duration, 0 hrs sleep, 6 antihistamines.	Realistic Fire Direction Center (FDC) tasks in an altitude chamber at 427 m. (control) and 4242 m.	Performance of primary tasks was measured.	48 hr continuous performance.	Control group showed circadian effects (more errors in early morning hours). High altitude performance was less efficient during first 10 hrs (but overlearned skills showed few errors even with acute mountain sickness). In last 38 hours, compensatory behavior kept performance at or above that of low altitude.	Stokes, et al. 1976.
48 hrs duration, 2 hrs sleep, 12 applicants for Ranger training.	Simulated patrol missions, radio, ambushes, first aid, weapon, land navigation, at a training area.	Logical reasoning, map plotting, and encoding-decoding tests. Physical fitness was also measured.	Subjects were kept physically active for most of the exercise. 2 hours' sleep were permitted after 30 hrs. Performance on probe tasks was measured at the beginning, middle and end of the 48 hours.	Cognitive work capacity declined, but physical fitness helped when the cognitive task was longer than 6 min and sleep loss effects were worst.	Picban, et al. 1985.
48, 44 & 36 hrs duration, 0 hrs sleep, 10 men.	"Multiple task performance battery" (3 vigilance tasks, 3 accuracy tasks, accuracy- perceptual, procedural).	(Measured performance of primary tasks.)	Continuous.	36, 44, and 48 hours continuous work resulted in 15%, 20% and 35% work efficiency decrements, respectively.	Morgan, 1974.
48 hrs duration, 0 hrs sleep, 142 task crewmembers.	Watching for a momentary light flash in 1 of 4 screens, and continuous simulated task scoring.	(Measured performance of primary tasks.)	Continuous pattern of 1 1/2 hrs work and 15 min break, except for 1 hr meal break every 6 hrs.	Large performance decrements resulted from 48 hrs of operation without sleep. Decrements occurred primarily at night, especially during the second night of the 48-hr period, when it was found impossible to keep the men awake.	Haggard, 1969.
48 hrs duration, 0 hrs and normal sleep, 142 soldiers.	Tracking a winding road on a driving simulator, and attempting to detect brief, infrequent light signals on a large screen, performed independently by members of 2-man teams.	(Measured performance of primary tasks.)	Continuous pattern of 1 1/2 hrs work and 15 min break, except for 1 hr meal break every 6 hrs.	Sleep deprived subjects did worse on the driving task than those with normal sleep. They also did worse on the detection task, especially in the period 0200-0700.	Drucker, et al. 1969.

Table 1. Experiment Summary Table, Page 4 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
48 hrs duration, 8 hrs sleep, 120 tank crewmn.	Driving tanks around a 36-mile circuit simulating tactical problems including offensive, defensive, and retrograde movements.	Communication, driving, surveillance, gunnery, maintenance.	The primary tasks were virtually continuous. Performance testing on probe tasks was of short duration, representing possibly arousing breaks in otherwise monotonous activities.	Activities demanding high alertness or complex perceptual-motor performance were most sensitive to sleep loss. The authors concluded that all other tasks would not have serious decrements during 48 hrs without sleep, but probe task procedure clouds that conclusion.	Alisworth and Bishop, 1971.
48 hrs duration, 0 hrs sleep, 10 artillerymen.	Simulated sustained- combat operations in the field artillery Fire Direction Center.	(Measured performance of primary tasks.)	Continuous. Scheduled for 84 hrs but subjects withdrew after 48 hrs.	Accuracy for unphased missions was generally maintained, but timeliness suffered. Accuracy as well as timeliness suffered for on-call missions against pre-planned targets. After 45 hrs, latencies were 1000% - 1200% above initial values. Latency of prioritizing targets increased 200% - 600% after 18 hrs.	Boaderet, et al, 1980.
54 hrs duration, 0 hrs sleep, 12 young women.	Continuously monitor and act upon info transmitted over a communication network.	Serial reaction time, simple iterative subtraction, encoding/decoding, complex iterative subtraction, and logical reasoning, embedded in the primary task.	All tasks embedded in 6 hr blocks, which were separated by 5-20 min breaks to eat, drink, use restroom.	Performance was relatively stable during 1st day but degraded sharply in the early hours of the 2nd day (0300) and never reached 1st day's level again. A similar abrupt drop was seen c. 0300 of the 3rd day. Correct reaction time performance was 76% on 2nd day and 51% on 3rd day, compared to first. Correct logical reasoning and subtraction performance was c. 69% on 2nd day and c. 36% on 3rd day.	Angus & Hestegrade, 1985.
66 hrs duration, 0 or 6 1/2 hrs/night (control) sleep, 20 young men for 2 days & 8 for 3 days.	Games, radio, TV, meals, conversation, walking.	Perceptual-motor (aligning a pointer as quickly as possible with whichever of 5 lamps illuminate).	12 min on task every 4 hrs.	Reaction times increased and movement times increased even more as a result of sleep loss.	Buck, 1975.
70 hrs duration, 0 hrs sleep, 20 volunteers.	Wakefulness, not otherwise specified.	Short test of ability to read and receive complex instructions.	Tested at 55th hr and 70th hr.	Time to read instructions was 26% and 33% longer compared to initial test; errors increased also.	Schein, 1957.

Table 1. Experiment Summary Table, Page 5 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
72 hrs duration, 24 hrs sleep, 24 subjects	Flying a link trainer; discrete info processing.	(Measured performance of primary tasks.)	Two 4 1/2 hour flights per day.	Flight performance showed fatigue and circadian effects. Info processing degraded, even though schedule permitted more sleep than would continuous operations.	Perelli, 1980.
72 hrs duration, 3 hrs sleep per 24 hrs, 14 young men.	Monitor each of 3 volunteers for pointer deflections which lasted 4.5 sec. One of 3 peak responses had to be pushed to make the corresponding meter viable.	(Primary task performance was measured.)	Continuous performance 50 min per hr. 10 min break given each hr.	Signal detection probability and latency showed a progressive decrement over the 3 days. Observing rate for variable-interval signals showed progressive loss of performance.	Frazier, et al, 1971.
72 hrs duration, 0 hrs sleep, 6 young men and 2 young women.	Visual search, addition and subtraction, logical reasoning, digit recall, pattern recognition, lexical decision, vigilance.	(Performance on primary tasks was measured.)	30 min of each hr were intended to be spent on performance tests with remainder free for inactive activities. However, as study progressed, subjects took longer to complete tests, spending c. 45 min/hr, leaving c. 15 min/hr for other activities.	A moderate continuous reduction in accuracy and much larger increase in reaction times was seen for all subjects on all tests. "Throughput" declined 74% (approx. 1% per hr). All subjects experienced perceptual distortions and visual hallucinations, as early as 24 hrs and as late as 64 hrs.	Thorne, et al, 1983.
72 hrs duration, 3 hrs sleep, 31 Army officers and corporals.	Firing with electro- optic rifles at simulated tanks moving across field of vision at varying speeds. Performance feedback was given every 3 hrs.	(Performance of primary tasks was measured.)	Continuous.	Speed and accuracy of shooting decreased throughout the 72-hr period. There were notable circadian depressions for both measures. There were pronounced increases in fatigue ratings, moderate increases in distress ratings, and confusion and hallucinations in 2 subjects.	Levi, 1972.
78 hrs duration, 0 hrs sleep, 20 soldiers	Staying awake by playing games, talking, or taking short walks.	40-min simulated radar-watching task.	The radar-watching test was given at 6, 30, 54, 66, and 78 hrs. Electric shocks were given during the final test only.	Correct detections fell from c. 100% at 6 hr, to 90%, 80%, and 70% at 30, 54, and 66 hrs. Electric shocks raised performance to 90% avg at 78 hrs, but it declined steadily throughout the 40-min test.	Bergstrom, et al, 1973.

Table 1. Experiment Summary Table, Page 6 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECT	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
90 hrs duration, 0 hrs sleep, 10 infantrymen.	Staying awake (doing map reading tests, transcribing, weapon- handling tests, 1.5 mi marching twice a day, small-bore rifle shooting, eating).	3 short encoding/decoding tests (c. 10 min ea.)	Tests were given at 1000 and 0230 each day.	After 3 nights without sleep the subjects' average cognitive performance was 59% of control values. Performance improved in the last test to 85%, attributed to anticipating the end of the experiment. On the 3rd day subjects were constantly dozing off, but were immediately awakened. They appeared to be in a daze.	Hastam, 1985.
96 hrs duration, 0 hrs sleep, 8 male and 8 female univ. students.	Staying awake.	Card sorting. The cards had various amounts of irrelevant information that had to be ignored.	Unknown.	When the task included irrelevant info, performance deteriorated more after sleep loss than it did on the same task without irrelevant info. The author suggests the result is due to failure of selective attention, which may be sensitive to sleep loss.	Norion, 1970.
100 hrs duration, 2 hrs sleep, 18 military academy cadets.	"Streamlined and continuous field operations" during a Ranger training course.	Digit-symbol code test (measures visual acuity, motor coordination, and speed of association), logical reasoning test, and a letter cancellation test (measuring perceptual speed). Each of the 3 tests was c. 5 min long.	The tests were administered 7 times during each 24 hr period at c. 4-hr intervals.	All tests showed substantial impairment. Day 4 levels were lowest, at 50-60% of baseline. Circadian variation was pronounced (plus or minus 20% - 40% for the various tests). A mood state score correlated highly (c. .90) with test performance.	Bugge, et al, 1979.
100 hrs duration, 0 hrs sleep, 13 men and 4 women.	Wakefulness, not otherwise described.	Reaction time, tapping, aiming, hand steadiness, color perception, visual acuity, depth perception, learning, memory, and performance on the A.C.E. psychological examination.	Tests were given from 0900-1300 each day.	Severe deterioration in the performance of most tests after 72 hrs. Subjects had to be awakened repeatedly during the tests. Clinically, at least 50 abnormal symptoms appeared, 12 of which appeared in all 17 subjects.	Edwards, 1941.

Table 1. Experiment Summary Table, Page 7 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PROBE TASKS	TASK SCHEDULE	RESULTS	REF
120 hrs duration, 4 hrs sleep/day, 6 pilots	"Flying" in a helicopter simulator.	Numerous flight parameters reflecting pilot performance were recorded.	14-hr missions for 4 days, 10-hr mission on 5th day. 4 hrs sleep per night.	Pilots maintained flight parameters within acceptable tolerance. However, various cognitive and judgemental errors were made, and flight weapons deemed them unsafe to fly by the 3rd night. Nevertheless it is noted that pilots continued to fly well.	Kreger, et al, 1963.
144 hrs duration, 3 days w/o sleep, 1.5 hrs/day sleep on final 3 days (control group got 4 hrs/day every day) 12 infantrymen.	Rifle shooting, grenade throwing, running, search digging, simulated casualty evacuation, weapon cleaning.	Vigilance rifle shooting (at pop-up targets), slow-fire grouping (firing at small group as possible), encoding/decoding, word memory, numerical addition.	Lab tests in mornings, rifle shooting in afternoons.	Only 3 of 6 subjects in the experimental group completed the experiment. Vigilance rifle shooting degraded (42% hits baseline vs. 26% hits on final day). Grouping performance was worse; groups on day 6 measured 125% of baseline. Encoding/decoding performance declined to c. 31% of baseline on day 6. Addition test measures were 58% and 35% of baseline on day 6. Memory test scores got worse also, c. 45% of baseline on day 6.	Haslam, 1965.
285 hrs duration, 0 hrs sleep, 4 young men.	Wakefulness, not otherwise specified.	Similarities and Logical Puzzles Tests, short term memory test, interaction test (group problem solving without verbal exchange), visual-motor tracking task.	Not specified.	The Similarities and Puzzles test performance degraded after 150 hrs, short term memory dropped sharply after 200 hrs, the interaction test was the same at the end as at 50 hrs, but tracking test errors increased markedly in 5th and 6th days; at 200 hrs even the simplest tracking task was impossible.	Passan, et al, 1968.
216 hrs duration; 0, 1.5, or 3 hrs sleep/day; 68 members of the Parachute Regiment.	Digging, camouflaging, mine laying, first aid, "casualty" evacuation, "many other activities."	Vigilance shooting, grouping capacity (shooting into as small an area as possible), weapon handling tests, cognitive tests, map plotting, short term memory, logical reasoning, Stroop test.	Shooting and weapon handling tests were given during daylight hours at the same time each day, and cognitive testing was done in early morning hours (0730-0700).	All of the no-sleep platoons withdrew after 4 nights. 45% of the 1.5 hr/day sleep platoon and 91% of the 3 hr/day platoon completed the exercise. Vigilance shooting degraded for all platoons, but not grouping capacity or weapons handling. There was a rapid deterioration in cognitive test performance for most tests and all platoons.	Haslam, 1981.

Table 1. Experiment Summary Table, Page 8 of 8

EXPERIMENT DURATION, SLEEP ALLOWED, SUBJECTS	PRIMARY TASKS	PHONE TASKS	TASK SCHEDULE	RESULTS	REF
216 hrs duration, 8 hrs sleep in the 1st 10 hrs & 4 hrs in 24 thereafter; 10 treated before surgery.	Digging, concealing, and alarm testing. First 4 hrs, "casualty" evacuation, "many other activities."	Vigilance shooting, grouping capacity (shooting into as small an area as possible), weapon handling tests, cognitive tests, map plotting, short term memory, logical reasoning, Stroop test.	Shooting tests during day, cognitive tests at 1300, 0100, and 0545.	After 90 hrs without sleep, the 1st 4 hrs block sleep had a marked beneficial effect upon performance. After a total of 12 hrs sleep over the next 3 days, performance had recovered (except for scores at 0545 hrs) from an average of c. 30% to 85% of control values.	Husam, 1982.

While the soldier load assessment method will accommodate the relatively dynamic tasks of walking or carrying loads over terrain, it is not capable of addressing fatigue issues induced by the static or mixed static and dynamic work of materials handling. The NIOSH Work Practices Guide (WPG) for manual, sagittal plane lifts represents a starting point (NIOSH (1981)).

Unfortunately, neither the soldier load nor the NIOSH WPG model predict time to fatigue. Additional development is needed to convert these to forms which are of use to the combat modeling community. In addition to the performance metric provided, one must pay careful attention to the conditions of their development and application. The SLA was developed to solve a tactical planning problem in light infantry divisions. If the Army continues with its plan to phase out such divisions, the model's relevance will fade. The NIOSH model was developed for sagittal plane, two handed lifts; asymmetric lifts, or pushing or pulling are not included.

In general, findings indicate that time to onset of physical fatigue is a function of the following conditions:

- percent of maximum aerobic capacity (percent VO_2 max measured for static or dynamic activity);
- perceived exertion;
- duration of activity;
- external load;
- thermal conditions (temperature and humidity); and
- duration of sleep deprivation.

Similarly, time to recovery could be determined from current workload, the duration of activity, duration of sleep deprivation, and opportunities for sleep. Specific coefficients and formulae cannot be derived with the available data or in the scope of this research, however.

Impact of Fatigue on the Combat Process

Although the literature indicates that fatigue is a significant factor in performance, especially in cognitive tasks, in the reality of combat, it is significant if and only if all other factors are equal. Results from analysis of after action reviews and the Digital Data Base at NTC conducted as part of this research effort, suggest that other factors are not equal, however. Therefore, it is important that we place the issue of fatigue in the proper perspective, and direct our focus on leadership and basic soldier skills such as command, control, and intelligence and unit positioning.

APPENDIX A
FULL SYNOPSES OF RELEVANT REPORTS

Document No: 063

Title: THE EFFECTS OF A 48-HOUR PERIOD OF SUSTAINED FIELD ACTIVITY ON TANK CREW PERFORMANCE

Authors: Ainsworth, L. L. and Bishop, H. P.

Agency: Human Resources Research Organization

Date: 1971

Hypotheses: 48 hours of sustained operations will have an impact on the performance of tasks performed by tank crews including communication, driving, surveillance, gunnery, and maintenance.

Stressor: 48-hours of activity without sleep.

Tasks: Radio telephone procedure; driving exercises, including crossing a log obstacle, driving through a ditch, maneuvering through a slalom course, and maneuvering through a simulated mine field; surveillance exercises, including passive surveillance where the tank was stationary and the task of the crews was to detect and identify a number of targets, and moving surveillance where the task of the tank crew was to find an aggressor machine gun and return fire as the tank moved along the course; gunnery exercises under three conditions: (1) tank stationary and stationary targets fired on with the main gun, (2) tank moving and stationary targets fired on with the coaxial machine gun, (3) tank stationary and moving targets fired on with the main gun and the 50 caliber machine gun; maintenance exercises including standard services and checks usually performed during operations such as engine oil level, transmission oil level, antennas, battery, water and cables, vision devices, exterior lights, and fuel and lubricant leaks.

Subjects: 120 men from the 2nd Battalion, 67th Armor, Ft. Hood, Texas. These were divided into an experimental group of 20 tank crews and a control group of 10 tank crews. The control group had 24 hours rest between each of 2 12-hour work periods. The tactical problem was of 12 hours duration and designed to utilize a specially constructed 35.7 mile long problem course. The problem included offensive, defensive, and retrograde movements. The performance tests were conducted at specified points along the course.

Results: The experimental group exhibited little performance decrement in the communication, gunnery and maintenance exercises, and in two of the driving exercises. The performance of the experimental group was significantly worse than that of the control group only in moving surveillance and in two of the driving exercises. The authors report that differences in performance in all exercises were small, as were the differences found between the scores obtained during the day and those obtained at night. They concluded that activities that demanded a protracted high level of alertness or complex perceptual motor activity,

such as the moving surveillance task and some driving tasks, were the most sensitive to the adverse effects of sleep loss. They also concluded that all other tasks could be performed without serious performance decrements during a 48-hour period without sleep, and that performance at night was not significantly affected by the diurnal rhythms of the subjects.

Critique: At best, the results of this study should be regarded as inconclusive in regard to the effects of 48 hours of sleep deprivation. The experimental procedure was seriously flawed in that virtually all performance testing was of short duration, represented a break in otherwise monotonous activities, and in general could be regarded as a highly alerting event. Some tasks were of a highly over-learned type where one would not expect performance decrements. On others, e.g., gunnery, performance was at such a low level there was little opportunity for degradation effects to be shown. Other tasks showed evidence of a learning curve which may have obscured circadian effects that the authors feel were not present. The study is open to a variety of other criticisms as well.

Document No: 304

Title: EFFECT OF SLEEP LOSS ON SUSTAINED COGNITIVE PERFORMANCE DURING A COMMAND AND CONTROL SIMULATION

Authors: Angus, R. G. and Heslegrave, R. J.

Agency: Defense and Civil Institute of Environmental Medicine, Ontario, Canada

Date: 1985

Hypothesis: Previous sleep loss studies may have provided conservative estimates of cognitive deficits that can occur during sustained intensive military operations because they employed tasks with low cognitive demands and performance assessment was infrequent.

Stressors: 54 hour period of wakefulness; requirement to continuously monitor and act upon information transmitted over a communication network.

Tasks: Four choice serial reaction time; simple iterative subtraction; encode/decode; complex iterative subtraction; logical reasoning; short term memory (digit span); auditory signal detection and vigilance; paired associate learning/recall; map plotting; and message processing.

The latter task required subjects to monitor communication networks which involved accessing, reading, understanding, interpreting, and filing information from a simulated military conflict. Some messages required short phrases to be typed onto a keyboard and some required a tactical map of the battle area be updated. Some questions required that summaries be written and manually filed. Manually filed information was necessary to answer questions asked in later messages. All of the tasks were embedded in 6 hour blocks, each of which contained 4 work sessions, with the same sequence of activities occurring in each block. The 6-hour work sessions were separated by rest breaks varying from 5-20 minutes during which subjects were permitted to eat, drink, and use the restroom.

Subjects: 12 female students recruited from the University of Toronto.

Results: The authors' contention that previous studies have provided conservative estimates of performance degradation as a function of sleep loss was confirmed by the findings. For example, earlier studies had shown that after one night without sleep the number of correct responses on serial reaction time tasks remained at about 90% of baseline. In the present study, performance fell to 76% of baseline. Whereas others had reported decrements to 79-90% of baseline after 2 nights without sleep, the present experiment showed performance dropping to 43% of baseline.

Similar differential results were reported for logical reasoning, which declined to 72% of baseline during the first night, and 41% during the second night; auditory vigilance showed similar results.

Subjective reports of fatigue, sleepiness and mood also showed greater degradations than earlier investigators had found. Subjective scales administered within work sessions showed differentially greater effects than scales administered following short rests. Similar results were observed for an embedded decoding task. The findings suggested that subjects are less able to maintain performance on tasks that are integrated with their primary function than on tasks that are distinct from their primary function.

Both message processing times and time required to answer questions contained in the messages showed a strong increasing function particularly during the early morning of the third day. Performance during the second day was poorer than during the first day, but by far the steepest performance degradation occurred during the night between days 2-3.

Critique: This study was methodologically superior to many other studies reviewed because of the requirements for continuous work and the embedded testing procedure. The greater severity of effects, compared to other studies using similar tasks, is an important finding. The only uncertainty regarding the outcome stems from the fact that the subjects were quite different in background and sex from those employed in most other studies of long term operations. This may or may not have made a difference in the outcomes.

Document No: 182

Title: SIMULATED, SUSTAINED-COMBAT OPERATIONS IN THE FIELD ARTILLERY
FIRE DIRECTION CENTER (FDC): A MODEL FOR EVALUATING BIOMEDICAL INDICES

Authors: Banderet, Lewis E., Stokes, James W., Cone, Ralph Frances,
and Kowal, Dennis

Agency: U.S. Army Research Institute for Environmental Medicine

Date: 1980

Hypothesis: The performance of FDC teams will be affected by "challenges" of extended duration (up to 86 hours) and also by performance-contingent positive and negative feedback concerning accuracy and timeliness of performance.

Stressors: Two 38 hour challenges separated by 34 hours of rest; one open-ended challenge designed to run for 86 hours if that were possible.

Tasks: Tactical battle scenario. Task demands were generated by radio messages, and were the tasks normally performed by FDC teams. These included responding to calls for artillery fires for unplanned missions, pre-planning in response to encoded pre-planned messages; prioritizing of anywhere from 2-16 targets at any point in time; responding to demands for artillery fires on pre-planned targets; revising pre-planned targets; updating to improve ballistic correction factors on pre-planned targets. Activity is associated with periods of intense fire missions.

Subjects: 5-man FDC teams comprised of volunteers from the 86nd Airborne Division. There were 4 teams in all.

Results: Team 1 withdrew from the study at 7:00AM after 48 hours of operations. Team 4 withdrew at 4:00AM after 48 hours of operations. These were the teams that were scheduled to go for as long as 86 hours.

Team 2 showed some deterioration in the second 38 hour challenge, with 3 team members having slept very poorly the previous evening. Team 3 completed both 38 hour trials with little performance deterioration, although they lost 1 operator after 6 hours of the second trial.

For all teams, accuracy of firing data for unplanned missions was generally maintained until exercise termination. In contrast, accuracy of firing data for pre-planned targets fired upon during on-call missions deteriorated for all teams. Errors were associated with omissions of correction factors in speed-accuracy trade offs. Although accuracy for unplanned missions was generally maintained, timeliness suffered in all but one team. Video review confirmed that speed was sometimes sacrificed for accuracy because of increased individual latency and double check procedures.

Timeliness as well as accuracy suffered for on call missions against pre-planned targets in teams 1 and 4. The quick responses to be achieved by pre-planning deteriorated markedly in teams 1 and 4 in those very

situations where responsiveness was judged to be tactically most crucial. After approximately 45 hours (0215 and 0400) latencies increased by a factor of 10-12 above initial values. A median response time of greater than 300 seconds was required by team 1 to deliver what artillery doctrine requires in less than 20 seconds.

Teams 1 and 4 also showed increased latencies for prioritizing. Changes 200-600% greater than initial values were evident after 18 hours in both teams.

The authors suggest that the quantity of work never done may be more useful as an index of team capacity and performance efficiency than increased errors or latencies. In the initial 36 hour period, this ranged from 5% to 38% for various teams. Teams 1 and 4 which worked for 48 hours showed values of 34% and 48% respectively.

The authors note that teams 1 and 4 ended their participation in the simulation at times corresponding to their circadian low points. They speculated that instruction, experience, leadership, and social support can attenuate the impact of these physiological effects.

The 86 hour single sustained operations challenge (for teams 1 and 4) was more demanding at equivalent points in time than the two 38 hour repeated challenges separated by 34 hours of rest. Performance deteriorations occurred earlier and were greater. The authors speculated that the implied mission demands and self and team doubts and uncertainties were responsible.

Performance deterioration appeared in most teams after 30-36 hours in the simulation. The authors suggest that adverse environments, real world situational uncertainties, and combat conditions would likely have additional disruptive influences.

Critique: This study has the merits of high task validity and meaningful team operations. It seemed well conceived and well executed. Motivation of the subjects should have been higher than in many laboratory studies and, as noted, performance feedback was given. This was not sufficient however to prevent significant deterioration in performance as well as eventual withdrawal from the study by the teams faced with long term sustained combat operations.

Document No: 427

Title: EFFECTS OF CONTINUOUS MILITARY OPERATIONS ON SELECTED MILITARY TASKS

Authors: Banks, James H., Sternberg, Jack J., Farrell, John P., Debow, Charles Henry, and Dalhamer, William A.

Agency: U.S. Army Behavior and Systems Research Laboratory, Arlington, VA.

Date: 1970

Stressor: Continuous operations testing for "nearly 48 hours."
(Target searching, travel in truck, tactical patrols)

Tasks: Target acquisition with a Starlight Scope; rifle shooting; accuracy of grenade throwing.

Subjects: 63 enlisted personnel from Experimentation Battalion, Camp Roberts, CA.

Results: No degradation in target detection time was found between night 1 and night 2 when using the Starlight Scope to search for targets. Mean detection times were actually somewhat better on night 2. Similarly, no differences in rifle shooting and grenade throwing accuracy were found between Day 1 and Day 2. It is concluded that "troops can be tactically employed for at least 44 hours without suffering any loss in performance in their use of Starlight Scopes or other military tasks such as rifle firing and grenade throwing, if their motivation is high".

Unfortunately, no baseline performance measures were presented against which performance during continuous operations could be compared. Further, the authors admit that the soldiers slept while being transported to various locations in trucks although they consider this a "natural" type of rest break that occurs during continuous operations. Moreover, when in the foxholes, two men worked on a 30 minutes on - 30 minutes off schedule while searching for targets. The total search time was only 2 hours before returning to the truck and then to the camp. Thus, there was ample opportunity for recovery naps between watches.

Critique: Whether "natural" or not, the conditions of this experiment created a set of circumstances where the absence of performance degradation should come as no surprise. Unfortunately, performance data on a presumed "recovery" day were not analyzed. Thus, the conclusion that no loss in performance will be experienced "for at least 44 hours" should be viewed with reservation.

Document No: 203

Title: EFFECTS OF CONTINUOUS OPERATIONS (CONOPS) ON SOLDIER AND UNIT PERFORMANCE. PHASE I: REVIEW OF THE LITERATURE

Authors: Balenky, Gregory, Balkin, Thomas, Krueger, Gerald P., Headley, Don and Solick, Robert

Agency: U.S. Army Combined Arms Combat Developments Activity

Date: 1986

Hypotheses: Lack of sleep or brief or fragmented sleep may have adverse effects on soldier and unit performance.

Stressors: Sleep loss.

Tasks: Not specifically addressed, since this is a review article. It is recognized that the effects of sleep loss may be different for different kinds of tasks.

Subjects: Not applicable.

Results: The following are selected observations or conclusions.

1. Tasks which primarily require physical performance are relatively immune to the effects of sleep loss.
2. The relationship between sleep loss and performance decrements on various cognitive tasks is well established (three effects include brief "lapses" in wakefulness, a steady state of reduced arousal, manifested by reduced capacity for sustained selective attention, and a lowering mood and motivational level with associated reduced initiative. The degree to which each of these mechanisms affects performance depends on the nature of the task.
3. There is a positive correlation between the length of a task and its sensitivity to sleep loss.
4. The more cognitively demanding the task, the greater is its sensitivity to sleep loss. In many tasks, accuracy of performance can be maintained under sleep deprived conditions if the speed at which those tasks are completed is slowed. For tasks that are externally paced, accuracy is compromised more quickly under sleep deprived conditions.
5. Tasks for which immediate feedback is given are more resistant to the effects of sleep loss.
6. Tasks which have been well learned and repeatedly practiced are more resistant to sleep loss effects.
7. Tasks which require short term memory utilization are sensitive to sleep loss.

8. Work load interacts with sleep deprivation, producing more severe effects when subjects are required to work continuously through the sleep deprivation period.
9. No amount of interest, motivation, or personal effort of any kind will be completely effective in counteracting the effects of sleep loss.
10. A variety of studies (both laboratory and field), indicate that after 48-72 hours without sleep soldiers become militarily ineffective. This is especially true of those with command and control responsibilities.
11. While physical strength and endurance are relatively unaffected by lack of sleep and can be restored by simple rest, sleep is required to restore cognitive performance.
12. Superior leadership cannot overcome large quantitative differences in the amount of sleep obtained.
13. Larger decrements in performance are identified sooner in experiments involving continuous work and embedded testing than in studies employing intermittent testing.
14. With just 3.5 - 4 hours sleep per night, well trained, highly skilled soldiers can successfully control and maneuver complex man-machine systems (aircraft) for 12-14 hours a day for at least 5 days.
15. Soldiers and units can remain militarily effective for 2-3 days without sleep. Cognitive abilities are the weak link in the chain of human performance in SUSOPS.
16. With continuous work, degradation in cognitive performance can be seen as early as 18 hours into a SUSOP.
17. The decline in performance in continuous work without sleep is at least 25% for every 24 hours of operation with the drop in performance occurring in a step wise function in the early morning (0400-0600). Initiative and motivation decline and parallel with cognitive performance.
18. Since command and control functions are very similar qualitatively and different in scale) from the level of the corps down to the level of the tank and infantry squad, SUSOPS will degrade performance at all levels.
19. There are wide individual differences in the amount of sleep required each night ranging from as little as 3.5 hours to as much as 10-12 hours. The vast majority of adults require 6-8 hours of sleep each night to maintain adequate, normal levels of daytime arousal.

20. Chronic restriction of sleep length to less than 4.5 hours each night is not possible this is the lower limit of sleep length plasticity for most individuals and failure to obtain at least 4 to 4.5 hours sleep each night results in a rapid deterioration of mood, motivation, and performance on even the simplest of tasks.
21. Even on restricted sleep schedules which allow more than 4.5 hours of sleep per night, there is a cumulative sleep debt reflected by increasing daytime sleepiness. This may be tolerated for several days or even weeks, but the sleep debt is never fully satisfied until recovery sleep is obtained.
22. Training soldiers under sleep loss conditions is not likely to be effective in improving performance under subsequent sleep loss conditions.
23. The recuperative value of sleep is dependent not only upon the total amount of sleep, but also upon the continuity of that sleep. Maximal recuperative value is obtained from sleep which is minimally fragmented.
24. Mild arousals are just as devastating to sleep continuity as full awakenings, and the apparent ability of a sleepy soldier to sleep in loud, noisy environments can be deceptive.
25. The placement of sleep within the circadian cycle also determines the recuperative value of sleep. The most recuperative value will be gleaned from sleep periods occurring during the troughs in the typical circadian rhythm of alertness.
26. Sleep inertia effects are performance decrements which are evident immediately upon awakening, and which can persist for 15-30 minutes after awakening from normal sleep. Sleep inertia effects are evident for a wide variety of tasks, particularly those requiring cognitive performance.
27. Partial prior sleep deprivation diminishes reserves for coping with a subsequent SUSOP.
28. In maneuver warfare there are definable limits which, if exceeded, result in the point of diminishing returns in performance effectiveness being reached with a potential for catastrophic failure. For SUSOPS the limits are between 2-3 days. For CONOPS with minimal sleep (i.e., less than 3 hours in 24) the limit is several days to a week.
29. Cognitive abilities are the weak link in human performance in CONOPS. 6-8 hours sleep each night will maintain cognitive performance indefinitely. 3-4 hours will maintain

cognitive performance for 5-6 days. Less than 3 hours each night will lead to rapid declines in cognitive performance and military effectiveness.

Critique: The authors appear to have considered a major part of the important literature. Their conclusions appear rather definite considering the uneven quality of the research, but may be as defensible as any that can be drawn at this point in time.

Document No: 496

Title: EFFECTS OF CONTINUOUS OPERATIONS (CONOPS) ON SOLDIER AND UNIT PERFORMANCE: REVIEW OF THE LITERATURE AND STRATEGIES FOR SUSTAINING THE SOLDIER IN CONOPS.

Authors: Belenky, Gregory L., Krueger, Thomas J., Balkin, Thomas J., Headley, Donald B and Solick, Robert E.

Agency: Walter Reed Army Institute of Research

Date: 1987

Stressors: Sleep deprivation - various amounts

Subjects: Military personnel

Results: A review of the literature with emphasis on CONOPS (continuous land combat with some opportunity for sleep that may be brief or fragmented) and SUSOPS (continuous land combat with no opportunity for sleep). For the most part, no data are presented.

This is similar to the previously reported review by the same authors (Document No. 203) but with some differences in content. In Chapter I a large number of conclusions are drawn including how certain mechanisms associated with sleep loss cause decrements in performance: (1) brief lapses in EEG defined wakefulness; (2) a steady state of reduced arousal during EEG defined wakefulness; and (3) by lowering mood and motivation levels.

Other conclusions include:

- After 48-72 hours without sleep soldiers become militarily ineffective.
- Mood, motivation, initiative, planning and preventive maintenance (both personal and equipment) decline.
- Superior leadership helps but cannot overcome large amounts of sleep loss.
- Cognitive performance is much more sensitive to adverse sleep loss effects than physical performance.
- Sleep deprivation results in a steady state of reduced arousal which is manifested by a decreasing capacity for sustained selective attention.
- The performance decrement with sleep loss depends on type of task being performed and, in particular, whether the task requires continuous concentration.
- Stepwise declines in performance over successive nights without sleep occur in association with the normal circadian trough in performance (0300-0600).
- 6 to 8 hours sleep each night will maintain cognitive performance indefinitely. 3 to 4 hours sleep will maintain cognitive performance for 5-6 days. Less than 3 hours sleep each night will lead to rapid declines in cognitive performance and hence military effectiveness.

It is concluded that soldiers and units can remain militarily effective for 2-3 days without sleep. On the other hand, it is noted that with continuous work degradation can be seen as early as 18 hours into a SUSOP. And, the decline in performance is at least 25% for every 24 hours of operation (p 1-8). It is suggested that command and control functions will be particularly impaired in a SUSOP.

Chapter II of this report presents strategies for sustaining the soldier in CONOPS. Included is a useful summary of the effects of sleep deprivation, taken from a report by the UK's Army Personnel Research Establishment. This is reproduced here.

Table 1: ARPE Summary

EFFECTS OF SLEEP DEPRIVATION

<u>Effects on Mental Processes</u>	<u>Tasks More Adversely Affected</u>
Lack of concentration	Sustained
Lapses of attention	Unstimulating
Reduced vigilance	Work paced
Slowing of action	Surveillance
Impaired short-term memory	Inadequately learned
	High Workload
Loss of insight	Complex decision making
Misinterpretation	
Visual illusions	
Disorientation	
<u>Mood Effects</u>	<u>Countermeasures</u>
Fatigue	Rest periods
Depression	Short naps
Irritability	Shorter work periods
Loss of interest in surroundings	Rotation of duties
and events	High state of training
Increasingly dominating	Realistic training
desire to sleep	Mental stimulation
	Cross-checking
	Clear and simple orders
	Written instructions

UK's Army Personnel Research Establishment, 1986; Army Code 71378

Document No: 162

Title: CHANGES IN THE CIRCADIAN RHYTHM OF PERFORMANCE AND MOOD IN HEALTHY YOUNG MEN EXPOSED TO PROLONGED, HEAVY PHYSICAL WORK, SLEEP DEPRIVATION, AND CALORIC DEFICIT.

Authors: Bugge, Jan Frederik, Opstad, Per Kristian and Magnus, Per M.

Agency: Norwegian Defense Research Establishment, Division for Toxicology, and Institute of Work Physiology, Oslo

Date: 1979

Hypothesis: Strenuous and continuous field operations will affect the circadian rhythm of performance and mood of military personnel.

Stressors: Sleep limited to roughly 1-2 hours during a 5-day Ranger training course involving more than 100 hours of continuous activities; caloric intake of approximately 1600 kCal/D whereas the expenditure was 8,000-10,000 kCal/D. Non test periods were characterized by "strenuous and continuous field operations", not otherwise described.

Tasks: (1) Digit-symbol code test, which is assumed to measure visual acuity, motor coordination, and speed of association (5 minutes); (2) logical reasoning test, calling for the understanding of sentences of various levels of syntactic complexity (assumed to measure "higher mental processes") (5 minutes); and (3) letter cancellation task, a perceptual speed test with a small motor component (5 minutes).

The tests were administered 7 times during each 24 hour period at approximately 4-hour intervals.

Subjects: 18 cadets at the Norwegian Military Academy

Results: All tests showed significant and substantial impairment during the Ranger course. The lowest level of performance occurred on day 4 with a reduction to 50-60% of the baseline values. 4 days were required (amount of sleep not specified) before there was full restitution of performance to baseline levels.

During baseline and recovery days all tests showed a circadian rhythm of performance (plus or minus 10% of the 24-hour mean) with the low values at night, most often with a trough around 0400.

During the Ranger course, the circadian variation was much more pronounced (plus or minus 40% for logical reasoning, plus or minus 30% for coding, and plus or minus 20% for letter cancellation). The greatest oscillation in performance occurred on day 4 when the subjects had been exposed to long lasting sleep deprivation and physical work.

A mood state score correlated very highly with perceptual and cognitive performance: .86 with code test scores, .90 with logical reasoning, and .90 with letter cancellation.

On the fourth day there were major fluctuations in arousal, and the subjects had to be awakened when they fell asleep during testing. The authors concluded that the subjects experienced brief periods of "micro sleeps" which may have been reflected in the substantial variability in performance between test occasions. The authors feel that the higher range of oscillation indicates that the combined effects of sleep loss and physical exhaustion potentiate the fluctuations of the natural circadian rhythm.

Critique: This study, good in many respects, can be criticized on two counts: (1) the failure to employ any operationally relevant performance tasks; and (2) the very short durations of the tests of psychological functions. This was partially compensated for by the large number of testing periods every 24-hours, but tests of longer duration might have shown earlier and more pronounced effects of the stressors. Despite extraordinary fatigue and loss of sleep, subjects are probably capable of considerable compensatory effort for tasks of only 5 minutes duration.

Document No: 499

Title: CONTINUOUS OPERATIONS STUDY (CONOPS) FINAL REPORT

Authors: Dewulf, Gene, A.

Agency: U.S. Army Combined Arms Combat Development Activity, Force Design Directorate, Ft. Leavenworth, Kansas

Date: 1987

Stressor: Fatigue due to sleep deprivation during CONOPS and SUSOPS.
Tasks: Different kinds of tasks are considered in a generic sense particularly those thought to be most susceptible to the degrading effects of sleep loss including: command and control, reconnaissance, logistical support, and communications.

Subjects: The primary focus is on personnel in the ground maneuver force.

Results: This is a compilation of results from research, from experience at the National Training Center (NTC), and from historical combat engagements concerning the impact of CONOPS on individual soldiers and unit effectiveness. The principal focus was on human performance degradation due to sleep deprivation during a high intensity European scenario. Over 400 research articles were reviewed. Conclusions primarily reflect those of studies that are reported elsewhere in this review. Interviews are conducted with 24 leaders who had had NTC experience within the prior 2 years. These focused on the training and organizational techniques used by unit rotations at NTC to enhance their CONOPS capability. In addition, a survey of existing combat models was conducted to determine ways that simulation techniques could portray CONOPS.

The following conclusions, among others, are drawn:

1. 6-8 hours of sleep per night maintains performance indefinitely.
2. 4-5 hours of sleep per night will maintain effective performance for 5-6 days.
3. After 36-48 hours of continuous work without sleep, 6 or less hours of sleep is generally inadequate to return to normal performance levels. 4-6 hours to sleep can raise performance levels from 50% of baseline to only 75% of the initial performance levels.
4. A combination of 12 hours sleep/rest is required to recover following 36-48 hours of acute sleep loss.
5. Where high cognitive workloads are involved, 24 hours of sleep/rest are recommended after 36-48 hours of sleep loss.

6. Cognitive abilities degrade more rapidly than physical strength and endurance; degradation of cognitive performance comes as early as 18 hours into sustained work.
7. Speed and accuracy are tradeoffs during sustained operations. Generally, accuracy will be sustained and speed will be sacrificed; however the likelihood of errors, especially errors of commission increases.
8. The decline in performance when working continuously without sleep is about 25% for every 24 hours of operation.
9. Mood, morale, initiative and motivation decline in parallel with cognitive performance.
10. When complex tasks are over-learned, performance deterioration can be staved off for up to 24-48 hours of sustained operations. (pp. 4-5).

It is reported that early rotations to the NTC often had problems with sleep deprivation. Recent rotations reportedly have done much better through delegation of critical tasks performed by key personnel. This reflects the unit's level of training and cross training, as well as operating procedures.

It is concluded that command, control and communication is the area most susceptible to performance degradation due to sleep loss, based on NTC experience. The particular areas of concern are decision making, troop leading, and operations security. It is reported (page 7) that the fatiguing effects of CONOPS are reflected in a decreased flow of information after the first 18 hours of sustained operations. Problems due to cumulative sleep loss are also reported to affect the performance of scout platoons and support platoons (pages 8-9).

A review of a number of models (admittedly not all those available) led to the conclusions that: (a) existing simulations do not portray the effects of sleep deprivation on performance during CONOPS; (b) there should be model input data variables associated with a time period or time distribution for humans to complete certain tasks; (c) there should be model input data variables associated with an error rate related to "man in the loop." It is stated that simulation models currently do not account for degradation in human performance from sleep loss because: (a) the length of combat scenarios is relatively short (24-36 hours); and (b) appropriate degraded data that represent a given task or process being performed by a soldier with a given amount of sleep loss are not available.

It is felt that AURA is the only model which has the potential to explicitly account for the work/rest cycle of a unit. It is reported that this model is being modified to represent loss of efficiency of a unit due to sleep loss.

It is suggested that the following variable inputs can be adjusted to implicitly portray the effects of CONOPS:

1. Target detection (scan and dwell duration, and detection error).
2. Weapon engagement (time to fire and subsequent rounds) and weapon accuracy due to degraded human interaction with the weapon system.
3. Report processing duration.
4. Time to load and unload supply trucks.
5. Travel time to and from supply destination point.
6. Time for engineer units to complete tasks.
7. Maintenance repair times.
8. Time to decontaminate units (page 11).

This report also includes reports reviewed elsewhere in this document (see particularly the joint WRAIR/AIR report by Belenky, et al. (1986 and 1987), and by Krueger et al., 1985). Case studies from WWII are included, as are the results of the interviews conducted with leaders who reported on the effects of continuous operations at NTC on the performance of their personnel.

Critique: The conclusions drawn in this document heavily reflect prior research and appear rather definite given the uneven quality of that can be reached at the present time.

The very important tie of the research results to operational experience during CONOPS at NTC is based entirely on subjective (interview) data which are not fully convincing. For example, only 5 of 24 respondents felt that continuous operations significantly degraded the performance of command, control and communications personnel. Five of 24 respondents felt that performance of scout platoons was significantly affected by CONOPS and 6 of 24 felt the performance of support platoons was adversely affected. However, 13 of 24 felt that the flow of information was significantly slowed, particularly in the late night/early morning hours. Future work should be directed toward more objective measures of these important effects.

Document No: 062

Title: THE EFFECTS OF SLEEP DEPRIVATION ON PERFORMANCE OVER A 48-HOUR PERIOD

Authors: Drucker, Eugene H., Canon, L. Dennis, and Ware, J. Roger

Agency: Human Resources Research Office

Date: 1969

Hypothesis: Nearly continuous work in the context of 48 hours of wakefulness will affect tracking performance and target detection tasks.

Stressors: Sleep deprivation for 48 hours; a continuous work pattern of 1 1/2 hours of work followed by a 15 minute break, repetitively, with a 1 hour meal break every 6 hours.

Tasks: Continuously tracking a winding road on a driving simulator; attempting to detect brief, infrequent light signals presented on a large screen. These two tasks were performed independently by members of 2 man teams. In some experimental conditions the subjects performed the same task throughout the experiment; in others, they rotated jobs after each 1 1/2 hour period.

Subjects: 142 enlisted men trained in armor, divided into experimental and control groups. Subjects in the control groups were allowed to sleep during the night hours.

Results: Sleep deprived subjects performed significantly worse on the driving task than the control subjects. They also performed more poorly on the target detection task, although there were no comparative data for the period from 0200 to 0700 because the control subjects were sleeping at that time. It was during this period when the experimental group showed its major performance decrement. The decrements were much larger during the second night than during the first night. Decrements in performance over the 48 hour work period were not eliminated by allowing the subject to rotate jobs periodically.

Under laboratory conditions large performance decrements occur when men perform a task for 48 hours without sleep. Decrements in performance occur primarily at night, especially during the second night of a 48 hour period.

The authors call for a field experiment to validate these findings, and speculate that the greater amount of activity in the field, as well as an increase in the motivation of the subjects, might reduce the magnitude of the performance decrements found in this study (see Ainsworth and Bishop (1971) for results of the field study).

Critique: This study has the merit of requiring the subjects to engage in relatively continuous performance. The marked circadian effects probably reflect the monotony of the task assignments although it

is interesting that the effect of task rotation was not appreciably ameliorative. It is noteworthy that neither the 15 minute breaks nor the 1 hour meal break every six hours was sufficient to prevent the decrement. Probably the principal criticism of this study is that the experimental tasks were less operational in flavor than they might have been.

Document No: 099

Title: MODERATE PHYSICAL WORK EFFECTS ON PERFORMANCE AND MOOD DURING SUSTAINED OPERATIONS (SUSOPS)

Authors: Englund, Karl E., Naitch, Paul, Ryman, David, and Hodgdon, James A.

Agency: Naval Health Research Center

Date: 1983

Hypotheses: Extended periods of continuous physical work will affect mental effectiveness.

Stressors: 2 20-hour continuous work episodes separated by 5 hours, including a 3-hour nap from 0400 to 0700. In addition to reduced sleep, experimental subjects walked a treadmill in full combat gear (25 Kg) at 31% max $\dot{V}O_2$ heart rate for a total distance of approximately 11 km per episode. Treadmill speeds ranged from 3.2 to 4.8 Km per hour depending upon the physical fitness of the subject. Distance covered in the 23 hours of baseline and continuous work episodes averaged 92.6 ± 9.6 Km, and ranged from 77 to 121 Km.

Tasks: Rapid alternation (a psychomotor test), simple reaction time, rifle disassembly/reassembly, a simulated Naval anti-air warfare task, and an air defense game. Psychological tests included a test of logical reasoning, auditory word memory, four-choice serial reaction time, visual memory, reading, and a visual vigilance task.

Subjects: 22 male Marines from a reconnaissance battalion at Camp Pendleton, California.

Results: The physical workload appeared to cause no significant decrements in performance. However performance decrements were found between the initial phase of continuous work and the end of the second continuous work period. These were judged to be the result of sleep loss and the circadian cycle. Performance decrements ranged from 9-55%. Simple reaction time increased by 10% to 33%. Vigilance dropped by about 10% in the second phase of the operation. Performance after the 3-hour nap (as measured at 0800) was not significantly different from the ending performance level of the first continuous work period. Visual vigilance showed a highly systematic difference throughout the performance period when comparing results during the first and second continuous work periods, with performance notably poorer in the second work period. The number of correct detections in the four choice serial reaction time test increased from baseline for control subjects (a learning effect probably) whereas it decreased for the experimental subjects.

The authors conclude that the physical work load did not significantly affect performance, but sleep loss and circadian effects produced performance decrements in some tasks. Decrements increased as the sustained operation stretched out into the long hours of night and early morning.

It was also concluded that physical workloads greater than 30% max VO₂ may produce more rapid and significant decreases in performance.

Critique: Unfortunately, few of the performance data are plotted as a function of time. Rather the authors depend on reporting results in terms of analysis of variance. Overall, the performance results are poorly reported, probably because of the investigators' central interest in physiological measures. It seems likely that the performance tests were too short, and of uncertain operational relevance, for adequately answering the question of how physical workload affects performance. As the authors themselves noted, greater physical workloads than those employed might have produced more rapid and significant decreases in performance.

Document No: 304

Title: COGNITIVE PERFORMANCE DURING SUCCESSIVE, SUSTAINED PHYSICAL WORK EPISODES

Authors: Englund, Carl E., Ryman, David H., Naitoh, Paul, and Hodgdon, James A.

Agency: Navy Health Research Center, San Diego

Date: 1985

Hypothesis: The combined effect of physical work and sleep loss, during episodes of continuous work, adversely affects cognitive performance.

Stressors: Only 1 3-hour nap during 48 hours of continuous work; walking the treadmill for a total of 6 hours where the treadmill speed was determined by heart rate and set to correspond to an energy expenditure equal to 30% of the subject's VO_2 max. A control group of subjects did not engage in physical work, but otherwise followed the same work schedules.

Tasks: An air defense game in which the player must decide an optimal time to launch a missile on the basis of target speed. The average range of intercept was the performance measure. The game, which lasts 30 minutes, is described as highly motivating, requiring sustained attention and timely decisions.

Cognitive tests included a logical reasoning test, alpha numeric visual vigilance task, auditory word memory test, visual memory test, four-choice serial reaction time test, and tests of reading comprehension, rate and efficiency.

When the experimental subjects took the vigilance test, they did so while walking the treadmill, wearing full combat gear, and carrying a pack and rifle. The control group took the same test in front of a video monitor screen while seated in a chair.

Subjects: 22 volunteer Marine reconnaissance personnel from Camp Pendleton, CA.

Results: Performance on the various tasks was differentially affected by sleep loss, physical work, and time of day. Performance on the alpha numeric visual vigilance test decreased by 10%, averaged across all subjects, on the 2nd continuous work day. Their ability to correctly identify objects of different shapes (shape memory test) also decreased by the same percentage. The authors state that exercise may have delayed the decrement in alpha numeric target detection for as much as 8 hours into the second continuous work day.

Control subjects who worked at sustained sedentary CRT monitoring suffered as much as a 12% decrement after just 1 day without some physical exercise between tasks. It was concluded that moderate exercise

while attending to a CRT may extend target detection performance levels 8 hours and may limit the performance decrement when it occurs.

The results also indicated that taking a 3-hour nap between successive 21 hour sustained operations had no immediate effect on performance of cognitive tasks (at least during the first part of the 2nd continuous work session).

Throughout the experiment the control group was able to remember the details of a recently read passage better than the experimental group. The authors feel that this result supports the work of Banderet, et al., (1980) whose subjects in the Fire Direction Center simulation began to ignore or miss important spoken message details after extended periods on duty, which resulted in endangering friendly troops. (See #182).

It is stated that there were no significant 2-way interactions for groups by days for any of the measures, indicating that the repeated moderate exercise combined with sleep loss did not have a direct impact on the cognitive functions measured in this study. It is claimed that this supports the findings of most other researchers who have not found performance decrements from exercise with sleep loss.

Performance on the air defense game, which the subjects found quite interesting, may have actually improved slightly over the course of the two continuous work days. It is speculated that performance on interesting/exciting tasks can continue to show learning trends up to 2 days in spite of numerous previous practice trials and moderate sleep loss. Competition and interest are seen as strongly motivating factors in this regard.

Finally, "the results from this study indicate that moderate exercise does not combine with sleep loss to further decrease cognitive performance. Variability at different times of the day, however, appeared to have a greater impact on cognitive abilities than the sleep loss or exercise levels."

Critique: During the continuous work sessions, subjects in the experimental group spent the first 30 minutes of each hour walking the treadmill while control subjects sat in front of a video monitor. The remainder of each hour was spent doing the various other tasks. This alternating period of walking and performing sedentary tasks may generate unique outcomes with respect to the complexities of physical and mental fatigue. Indeed it would not be surprising that the walking tasks served as an arousing stimulus for many of the subsequent, more sedentary tasks. Whether the level of energy expenditure (30% of VO_2 max), which the authors described as a "moderate level" of effort was in any way comparable to what troops might encounter under combat conditions is a matter not addressed in the article.

Document No: 552

Title: SELF-PACED HARD WORK COMPARING MEN AND WOMEN

Authors: Evans, W. J., Winsmann, F. R., Pandolf, K. B., Goldman, R. F.

Agency: U.S. Army Research Institute of Environmental Medicine

Date: 1980

Hypothesis: Individuals of different VO_2 max and body composition adopt different rates when working hard at their own pace and therefore move at different speeds.

Stressors: Four different terrains (heavy brush, light brush, dirt road, and blacktop road) and three different external loads (0, 10, and 20 kg backpacks) were studied. Subjects were requested to walk over the terrain in as short a time as possible.

Time on course was used to determine speed and energy expenditure.

Tasks: Walk on varying terrains (actual) with load.

Subjects: 6 male and 6 female subjects, fit.

Results: Walking speed and energy expenditure of the males were found to be significantly greater than those of the females over all terrains and for each load carriage condition. Relative energy expenditures (% VO_2 max) of the males and females for all conditions were very similar and constant at a value close to 45% VO_2 max. Females are remarkably consistent in maintaining the same self-paced "hard" energy expenditure regardless of the load. Results indicate that the voluntary hard work rate is dependent upon maximal aerobic power.

The best predictor of speed for self-paced hard work of males and females for 1 to 2 hours duration appears to be based on 45% of maximal aerobic power. Changes in work duration or external load could change the self-pacing rate, and the resulting % VO_2 max.

The above suggests that a value close to 45% VO_2 max may be a better predictor of troop mobility for heterogeneously fit populations than the maximal voluntary pace of 494 W (6.96 kcal/min). The men tended to adjust their individual pace much closer to 494W than did the women, but both men and women worked at nearly the same percentage of their maximal aerobic power for the 1 to 2 hr duration throughout the study.

Critique: The nature of the task and subjects, and the use of real-world terrain enhance the value of the study. The duration, between 1 to 2 hours, is quite short, but subsequent studies by this lab have addressed this issue (see Levine et al., 1982, #553).

Document No: 285

Title: HUMPRO STUDIES IN CONTINUOUS OPERATIONS

Author: Haggard, Donald F.

Agency: Human Resources Research Organization

Date: 1970

Hypotheses: (1) When little physical labor is required, crew tasks having high cognitive, perceptual, or perceptual-motor loadings will be susceptible to significant fatigue decrements from long term operations; (2) The diurnal cycle will have a significant effect on performance; (3) Varying tasks by means of job rotation will lessen decrements only if the job includes tasks with different human requirements.

It was stated that these hypotheses are in conflict with generally accepted military opinion which holds that: (a) men performed similar jobs, particularly during WWII for much longer periods (than 48 hours) without any perceived performance decrements; (b) allowing men to sleep until just before a night operation overcomes any diurnal effects; and (c) job rotation within a cross-trained tank crew prevents endurance decrements.

Stressors: 48 hours without sleep (1 1/2 hours of work followed by a 15 minute break, repeated continuously except for a 1 hour meal break every 6 hours).

Tasks: (1) A continuous surveillance task requiring the subject to respond to a momentary light flash in one of four scenes; and (2) a continuous simulated driving task employing a tank steering wheel, a light source, and a moving belt that represented a winding pathway. Photo cells behind the belt were activated by the light source when the men steered improperly, providing a measure of time off the pathway.

In a second study, five basic types of activities in armored combat gunnery surveillance, communications, driving and maintenance were employed. (The results of this second study are reported in document 063 by Ainsworth and Bishop, (1971)).

Subjects: 142 enlisted men trained as tank crewmen.

Results: Large performance decrements resulted from 48 hours of operation without sleep. Decrement occurred primarily at night especially during the second night of the 48 hour period. During the second night the experimenters found it impossible to keep the men awake.

Job rotation had mixed effects, possibly reducing the decrement in driving (which might induce unique muscular fatigue) but not reducing the decrement in surveillance.

The author concluded that this study should be repeated (it was, see Ainsworth & Bishop, 1971, summarized earlier) in the field where performance decrements of the type found in the laboratory might be negated by the increased crew motivation expected in a field operation.

Critique: The experimental tasks employed in this study probably represented an extreme insofar as tedium and continuous performance demands are concerned. It is clear that task motivation per se was inadequate for maintaining performance or even wakefulness. Whether or not the increased motivation of operating in the field would overcome these effects is problematic. Unfortunately the subsequent field study by Ainsworth and Bishop failed to answer the question because of the design limitations of that study (see synopsis for Ainsworth and Bishop in this section.)

Document No: 106

Title: THE MILITARY PERFORMANCE OF SOLDIERS IN CONTINUOUS OPERATIONS: EXERCISES "EARLY CALL" I AND II.

Author: Haslam, Diana R.

Agency: Army Personnel Research Establishment (U.K.)

Date: 1981

Hypothesis: The amount of daily sleep (0, 1.5, or 3 hours) will affect the performance of soldiers engaged in continuous operations over a 9 day period.

Stressors: (1) Total, or extensive sleep deprivation for up to 9 days; (2) Various physical activities associated with a defensive role against a small number of "enemy" troops. In Early Call II (at least) this involved digging, camouflaging, and occupying a full section defensive position. Other activities included mine laying, mine clearing, first aid, and casualty evacuation. There were "many other activities" throughout each 24 hours that took up much of the day and night.

Tasks: (1) Vigilance shooting, a test which combines vigilance with shooting at targets at ranges of 100, 200 and 300 meters which were briefly exposed (5 seconds). This task was of 20 minutes duration and involved 9 rounds of fire; (2) grouping capacity, which required the subject to fire five rounds of shots into as small an area as possible; (3) weapon handling tests including filling the magazine by hand, loading and unloading the rifle in a standing position, stripping the rifle and assembling the rifle; and (4) cognitive tests including encoding/decoding, map plotting, short term memory (digit span), logical reasoning, and the Stroop test.

Subjects: Three platoons consisting of 68 members of the Parachute Regiment.

Results: All of the platoon that received no sleep withdrew from the exercise after four nights; 39% of the group receiving 1.5 hours sleep withdrew by day 5, but 48% of that platoon completed the entire exercise. 91% of the platoon receiving three hours sleep completed the exercise.

For all three platoons, vigilance shooting was significantly worse under sleep deprivation than under control conditions. However, there was no overall deterioration with sleep loss in regards grouping capacity. The same was true for weapons handling tests.

For the majority of the cognitive tests, there was a rapid deterioration in performance over the first four days of sleep loss. In most tests, for all three platoons, performance on the experimental days was significantly worse than on the control days, and there was a significant deterioration over the sleep deprivation days. Performance on the cognitive tests in general was not significantly different for the three groups. The author concludes that the results of the cognitive tests

reflected not only sleep loss but also decreased morale and motivation, although it was stated that morale of the company generally remained good.

The author concludes that even small amounts of scheduled sleep were beneficial. Tasks with a mainly physical content suffered the least, and those with a cognitive and vigilance component suffered most, deteriorating to about 50% of control values over the first 4 days of sleep loss. Experienced military observers considered that physical tasks were carried out at an acceptable level by the 0 hours sleep platoon for three days, by the 1.5 hours sleep platoon for 6 days, and by the 3 hours sleep platoon for 9 days.

The conclusions with regard to Early Call II was that there was a clearly demonstrable and quantifiable impairment of cerebral function as well as military performance in the absence of sleep for more than 48 hours; the effect could be offset to a limited but useful extent by as little as 4 hours sleep per day; (for reasons that could not be discussed) the stimulus of battle is unlikely to be sufficient to offset the impairment adequately.

Critique: These were very ambitious studies with a high degree of environmental and task realism. A wider diversity of performance tests might have been selected and it would have been preferable for some tests, e.g., vigilance shooting, to have been of longer duration. Also some highly over-learned tasks were selected which would not be expected to show much decrement in performance, especially for short periods.

It was necessary to administer both the performance and cognitive tests at a remote site each day. This undoubtedly introduced a "test taking effect" so the results, if anything, are probably conservative. An exception to this however is that the cognitive testing took place between 0230 and 0700, a time when one would expect circadian effects to be greatest.

Document No: 170

Title: SLEEP LOSS, RECOVERY SLEEP, AND MILITARY PERFORMANCE

Author: Haslam, D. R.

Agency: Army Personnel Research Establishment (U.K.)

Date: 1982

Hypothesis: 4 hours of block sleep will have a beneficial affect upon the performance of soldiers who have had virtually no sleep for 90 hours. Long periods of sleep may be necessary for full recovery.

This study is an extension of the methodology used in Early Call I and Early Call II, but with a greater emphasis on the recovery function.

Stressors: (1) 9 day (216 hours) tactical defensive exercise. 3 3/4 days (90 hours) with no scheduled sleep and very little unscheduled sleep; and (2) Physical work (digging of trenches, camouflaging, etc.) and response to surprise attacks by "enemy troops"; mine laying, mine clearing, first aid and casualty evacuation.

Tasks: Vigilance rifle shooting, grouping capacity, and cognitive tests (logical reasoning and decoding, using a military cipher).

Subjects: 10 trained infantrymen.

Results: Performance on vigilance rifle shooting was systematically lower during the no sleep period than during either the control periods or the scheduled sleep periods. Performance was about 25% below the mean value for control days. There were no systematic differences in grouping performance.

Scores on logical reasoning showed marked degradation as a function of time without sleep as well as pronounced diurnal effects. When test sessions were scheduled at 0045 hours most of the subjects were unable to start the logical reasoning test within 5 minutes of awakening. Decoding showed similar marked decrements during the no sleep days.

Four hours sleep per 24 hours appeared to be sufficient for vigilance rifle shooting to return to and be sustained at nearly the control level. Four hours sleep was not, however, sufficient for recovery to control levels on the reasoning tests, and it was not sufficient for recovery on the decoding test when that test was given at low points in the circadian rhythm. After a total of 12 hours sleep over three days it was reported that performance had recovered from an approximate average level of 50% to 88% of control values. (Except for tests given at 0045 hours). However, 1 1/4 days (30 hours) of rest, of which an average of 19 1/2 hours was spent asleep, was necessary to eliminate any remaining performance decrement.

Critique: This study, like its predecessors, was well done. One might again argue for testing on a broader scope of representative military tasks as well as a longer period of performance on critical tasks such as vigilance rifle shooting.

Document No: 304

Title: SUSTAINED OPERATIONS IN MILITARY PERFORMANCE

Author: Haslam, Diana R.

Agency: Army Personnel Research Establishment (U.K.)

Date: 1985

Hypothesis: Small amounts of sleep will significantly improve performance during 6 days of operations.

Stressors: 3 days without sleep following 3 days with only 1.5 hours of sleep every 24 hours (the control group had 4 hours of sleep every 24 hours for 6 days).

Tasks: Vigilance rifle shooting; grouping capacity; and cognitive tests including a map grid reference encoding/decoding test using a military cipher, a word memory test, and an addition test. All of the tests were of short duration.

Vigilance rifle shooting was a 20 minute test in which subjects, in a prone position, fired at randomly appearing silhouettes of human targets, exposed for 5 seconds each, at ranges of 100, 200, and 300 meters. The subjects fired one round at each target and there were 9 targets in all. Feedback on performance was given.

The grouping capacity test measured the ability to fire 5 rounds so that the shots fell in a very small area. Firing was at an aiming point 100 meters distant. Grouping capacity tests were carried out daily at 1230 hours.

The subjects engaged in other activities more or less continuously day and night. Mornings were taken up with laboratory tests, afternoons with physical activity including rifle shooting on the ranges, grenade throwing, and running. Other more sedentary tasks were carried out for 3 hours in the early evening. Trenches were dug for 3 hours prior to midnight and a 2 hour simulated casualty evacuation exercise was carried out from 0530 to 0730. When the control group was asleep, the experimental group engaged in weapon cleaning.

Subjects: 12 trained infantrymen.

Results: Only 3 of the 6 subjects in the experimental group completed all trials. All 6 subjects in the control group completed the trial. By the end of the total sleep deprivation phase, the survivors in the experimental group had had no scheduled sleep for 85 hours, and a total of only 4.5 hours over the previous 67. No subject withdrew from the trial voluntarily. It was stated that no one in the experimental group had more than a few minutes of sleep at a time throughout the trial and the total amount of sleep taken was less than 30 minutes. The control group subjects apparently did not require unscheduled sleep, although they felt tired.

The difference in performance between experimental and control groups in vigilance rifle shooting was not significant. The author suggests that one reason could be the large variation in performance between subjects within groups as sleep deprivation increased. Degradation of performance across days was highly significant for the experimental group. 62% of the targets were hit on baseline and recovery days, but only 25.6% on the 6th trial day. No comparable degradation was found in the control group.

With respect to grouping capacity, experimental group performance on days 4, 5 and 6 was significantly worse than on baseline days. It was stated that the percentage deterioration in performance on day 6 compared with performance on baseline and recovery days was 125.9%. No comparable degradation in performance was observed with the control group.

The experimental group showed a significant deterioration in performance on the encoding/decoding test, whereas the control group did not. On day 6, at 0430, their performance was 34.7% of baseline for encoding and 27.7% for decoding. When tested at 0930 the comparable figures were 38.8% for encoding and 24.8% for decoding. Analysis of errors indicated a sacrifice of accuracy for speed.

Performance of the experimental group also deteriorated significantly in the addition test, whereas the control group performance did not. Different measures on the 6th day showed performance at 57.8% and 24.5% of baseline values.

Finally, in the memory test the experimental group recalled significantly fewer items than the control group, although performance deteriorated significantly for both groups. For the experimental group performance on the 6th day was at 43.6% and 45.1% of baseline values.

The error rate in all three cognitive tests increased over the test period for the experimental group.

The author reports that during the 6th day, the subjects had to be continuously prevented from dozing off. She was impressed with the fact that performance was still 37% of that on baseline days. The results for the control group confirmed earlier work which suggested that 4 hours of sleep in every 24 was sufficient to maintain a level of performance not significantly different from baseline value.

The average amount of recovery sleep taken was 16.75 hours for the experimental group and 12.83 hours for the controls.

Critique: The most general criticism of this research is that the test periods, both rifle shooting and cognitive testing, were of such short duration. This maximizes the possibility of short term mobilization of effort even with subjects as sleep deprived as these subjects were.

Some of the between group comparisons may have suffered from the rather small number of subjects (6) in each group. As the author noted, there were large individual differences in response to the stress condition.

Document No: 565

Title: ENERGY COST OF "HARD WORK"

Authors: Hughes, A.L., and Goldman, R.F.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1970

Hypothesis: Men working hard tend to adjust their work level to work at energy expenditures of 425 kcal/hr \pm 10% regardless of the terrain or load carried.

Stressors: Subjects carried loads ranging from 0 to 60 kg., over a 6 day experiment. Loads were carried primarily on the shoulders in vests and web belts.

Subjects completed 6.4 km or 80 minutes on treadmill, whichever was completed first.

Tasks: Walk for time or distance with loads at a comfortable pace which permitted them to complete the 4 miles.

Subjects: 12 male soldiers.

Results: Results showed that the average progression rate decreased nearly linearly with increasing load; the energy expenditures for the non-zero load conditions fell within the expected range of 425 kcal/hr, and the most economically carried loads (least cost per kilogram-meter) under the conditions of the study were 30 and 40 kg.

All subjects did not complete either the distance or the time requirements; two failed to complete 6.4 km or 80 minutes with the 50-kg and three failed with the 60-kg load.

When walking with a load, maximal efficiency is obtained at a comfortable speed, presumably averaging 5 km per hr with a load weighing 40-50% of body weight.

Critique: This is one of the first of several studies by USARIEM to assess energy cost of hard work, and feasible limits to operator workload. As such, it dealt with only a few variables, and restricted walking to a treadmill. Subsequent studies have conducted trials over a variety of terrain and load configurations.

Document No: 586

Title: EFFECTS OF SUSTAINED MANUAL WORK AND PARTIAL SLEEP DEPRIVATION ON MUSCULAR STRENGTH AND ENDURANCE

Authors: Legg, S., and Patton, J.

Agency: Army Personnel Research Establishment, Farnborough, UK

Date: 1987

Hypothesis: Specific physiological performance effects exist after a military 8-day artillery field exercise designed to include sustained manual handling of 45 kg artillery shells.

Stressors: The experimental group prepared, handled and loaded artillery shells and charges (weighing 45 and 12 kg respectively), throughout the trial. The control group simulated MMH activities but did not handle any real loads. The control group did no MMH.

Lower and upper body anaerobic power was assessed before, within 6 hours of trial completion, and after trials. Lower body anaerobic power was assessed using the Wingate test on a cycle ergometer. An isometric right hand grip strength was measured using a hand dynamometer before, during, and after the trial. Isometric contractions were performed by the subjects while standing and holding the dynamometer with their arm down by their side.

Tasks: Those involved in a real combat scenario for artillery gun crews. Tasks involved frequent moves of gun position and all the normal military duties such as digging of defensive positions, preparation of camouflage, meal preparation and simulated defense from infantry ground attack.

Subjects: 25 fit, experienced artillery soldiers. Eighteen of the soldiers acted as an experimental group and seven as a control group.

Results: The daily amount of sleep observed by each group was similar (3 to 4 hours). Isometric right hand grip strength for both groups fell progressively during the trial and did not return to pre-trial levels during 3 days of recovery.

At the end of the 8 day trial, there were statistically significant reductions in the body weight, body fat, and upper body mean power of the experimental group but not in the controls. Lower body peak and mean power were significantly increased at the end of the trial in both experimental and control groups. Lower body power decrease was significantly increased (18%) in the experimental group but not in the controls.

The isometric hand grip strength data suggest that sleep played a significant role since both experimental and control groups demonstrated a gradual progressive decrement in right hand grip strength during the trial. The decrease in mean power in only the experimental group suggests that there may also have been a partial depletion of upper body intramuscular energy sources or in the rate at which stored energy may be broken down.

The right hand grip strength did not return to pre-trial values during the 3 post-trial recovery days. Since hand grip is reported as an indicator of general muscular strength, it is possible that general body muscular weakness may persist for at least three days following a prolonged 8-day sustained high intensity military exercise.

It is suggested that the increase in lower body anaerobic power may be associated with the increased level of physical activity during the trial (i.e., a training effect), and that the decrease in upper body anaerobic power may be associated with the combination of unaccustomed arduous manual handling of heavy loads and partial sleep loss since it was only observed in the experimental group.

Critique: This is one of the most operationally relevant studies to assess the effects of sustained manual work. However, the study fails to document the frequency of artillery shell handling, nor does it quantify the exertions required by the other physically stressful tasks performed during the exercises (e.g., digging defensive positions, etc.) which both control and experimental group performed. Thus, it is difficult to isolate the effect of sleep loss from other non-documented work with regard to loss of grip strength.

Nonetheless, this, as well as other studies, point out the need to consider both upper and lower body strengths capabilities when assessing manual material handling tasks.

Document No: 515

Title: A PHYSIOLOGICAL STUDY OF THE REPETITIVE LIFTING CAPABILITIES OF HEALTHY YOUNG MALES

Authors: Legg, S. J. and Pateman, C. M.

Agency: Army Personnel Research Establishment, Farnborough, UK

Date: 1984

Hypothesis: Lifting rate affects time to exhaustion when soldiers move loads of three different weights between the floor and a platform at waist height.

Stressors: Repeated lifting of loads, lifted bimanually from the floor to a platform situated at waist height directly in front of the subject. Lift frequency was varied for maximal lifting capacity (MLC) as follows: 2, 3, and 4 lifts per min (75% MLC), 4, 6, and 8 lifts per minute (50% MLC), and 8, 10, and 12 lifts per minute (25% MLC). Lifting continued for 60 minutes or until subject became exhausted or was unable or unwilling to continue, or was unable to maintain the prescribed lifting rate or heart rate reached 180 beats/minute. Climate and clothing factors were not considered.

Tasks: Soldiers moving loads of varying weights to and from varying locations. Lifting performed with a bimanual squat lift, with straight back, from the floor to waist height.

Testing trials occurred after period of physical training (running and weight lifting). VO_2 max and isometric muscle strength were measured prior to the trials, as was maximal lifting capacity using a "modified" psychophysical method (not called out in text).

Subjects: Eight healthy, fit, well-trained infantry soldiers completed the study.

Results: Reaction time and lifting time were significantly longer when the subjects became exhausted (i.e., failed to complete the full 60 minute experimental run). Both indices were significantly longer at the end of exhausting lifting when compared to the middle period of that particular experimental run. The results suggest that the indices may be of value as practical indicators of general fatigue and in assessing the ability of individuals to continue lifting.

The most frequently reported factors which limited lifting capabilities included low back pain, general fatigue, and an inability to maintain an adequately secure grip of the pallet handles, particularly with the 75% load at the higher lifting rates.

Values for 75, 50 and 25% of MLC were 67.2, 44.8, and 22.4 kg, respectively.

If the major component of the task is repetitive lifting, 23% of VO_2 max (from the treadmill test) should be used as the guide to the maximum load lifting rate combination that will not induce fatigue over an 8 hour work day.

Critique: Observed lifting durations were available for only 47% of the trials (i.e., more than half of the trials lasted the full 60 minutes, rather than terminating due to stated thresholds), making it difficult to estimate the lifting duration for larger occupational groups. The recommended workload expressed as % of VO_2 max, for lifting tasks is in contrast to the limit provided for cycle ergometry or treadmill walking, and with good reason. The nature of the task, and the load imposed by upperbody, static exertions serves to restrict the oxygen transport mechanism and should be reflected in lowered workload expectations.

Document No: 202

Title: 7 PSYCHOLOGICAL AND PHYSIOLOGICAL REACTIONS AND PSYCHOMOTOR PERFORMANCE DURING PROLONGED AND COMPLEX STRESSOR EXPOSURE

Author: Levi, Lennart

Agency: Karolinska Institute, Sweden

Date: 1972

Hypothesis: A wide variety of physiological stress responses will be seen in subjects engaged in long periods of continuous performance (simulated rifle fire).

Stressors: Three days and three nights (72 hours) on a simulated range; "authentic battle noise" from a tape recorder played at a level of approximately 95 dB-C.

Tasks: Firing from a fixed position at simulated tanks moving across the field of vision at unpredictably varying speeds, which rapidly disappeared beyond the horizon of the shooting range and reappeared again after a perceptually changing interval. The subjects used "electronic" rifles which produced light beams when fired at the target tanks on which photo diodes were mounted. Subjects were given performance feedback at the end of each three hour period.

Subjects: 31 Army officers and corporals attending platoon leader training school.

Results: Performance was evaluated for speed and accuracy, as reflected in the number of shots and the number of hits. Both the number of shots per 3 hour period and the number of hits decreased throughout the 72 hour period; in addition there were notable circadian depressions for both performance measures. These reactions did not coincide with, but were preceded by a pronounced drop in adrenalin excretion.

In addition, there were significant and pronounced increases in fatigue ratings throughout the study, moderate increases in distress ratings, pronounced but transient confusional reactions in two of the subjects, including some hallucinations.

Critique: This was a well conceived and controlled laboratory study involving an interesting simulated combat task. The degree of immobilization of the subjects probably created an additional stressor that might not be characteristic of extended periods of combat. Nonetheless, it is of interest that the subjects' performance progressively deteriorated, and showed notable circadian effects, despite systematic performance feedback which some investigators suggest will do much to ameliorate fatigue effects.

The principal interest of the investigator was in the physiological correlates of these stress conditions. An exceptionally thorough job was done in this regard both in terms of the number of measures taken and the

facilities available for analysis. Marked and significant increases in adrenalin secretion and in protein bound iodine were noted as well as a marked and significant decrease in serum iron. If we become concerned with physiological correlates of behavior under stress, this paper is an excellent source.

Document No: 553

Title: PROLONGED SELF-PACED HARD PHYSICAL EXERCISE COMPARING TRAINED AND UNTRAINED MEN

Authors: Levine, L., Evans, W. J., Winsmann, F. R., and Pandolf, K. B.

Agency: U.S. Army Research Institute of Environmental Medicine

Date: 1982

Hypothesis: Well-trained subjects exercising at self-paced intensities for prolonged periods of time (up to 8 hours per day) reduce their energy expenditure to below 40% VO_2 max.

The study compared walking speed, heart rate, and predicted energy expenditure in trained and untrained men during a prolonged (2.5 - 3.5 hours) self-paced load carriage walk over varied terrain.

Stressors: Four different terrains (heavy brush, light brush, dirt road, and blacktop road) were traversed consecutively, for a total of three complete trails on each day (17.07 km). Subjects were instructed to walk at a fast pace which would feel like hard physical work, but which could be maintained for the full three rounds of the course.

Three different external loads were used: 0, 10, and 20 kg US Army backpacks.

Time on course was used to determine speed and energy expenditure.

Tasks: Walk a 17 km route over four terrains at a fast pace with load.

Subjects: 6 healthy trained and six healthy untrained male subjects (soldiers).

Results: Walking speeds for the trained and untrained groups were not significantly different. Walking speeds were slower for the heavy brush terrain, and during the 20 kg load carriage, compared to the 10 kg and no load conditions.

Mean heart rate for the untrained men was significantly higher than the heart rate for the trained men over each of the four terrains. Terrain changes affected the combined groups with heart rate increasing as the terrain became more difficult.

When predicted energy expenditure is expressed as a % of VO_2 max, the trained men were shown to walk at 35% while the untrained men walked at a higher relative cost of 44%. The differences were significant. Interestingly, the relative energy expenditures represented similar predicted absolute energy expenditures.

As the duration of exercise increased from 1 to 3.5 to 6.5 hours, individuals appeared to select decreasing relative energy expenditures from 46 to 40 to 36% of VO_2 max. Also, the more fit subjects may have been limited in their self-pacing attempts by being asked to refrain from running and by carrying relatively light external loads.

Critique: This study compliments that presented by Evans et al. (1980), No. 552, in the use of terrain and nature of the task. It enhances the study with a focus on prolonged exertion and the net effect on energy expenditure. Unfortunately, they do not measure individual energy expenditure, but rather predict it using the equation presented in Evans et al. As mentioned by the authors, the relatively light loads considered in the study may have kept some of the more physically fit subjects from reaching their most desirable "hard work" pace. This may have led to the decrease in % VO_2 max with increased duration of self-paced exercise.

Document No: 555

Title: SELF-PACING DURING SUSTAINED, REPETITIVE EXERCISE

Authors: Myles, W. S., Eclache, J. P., and Beaury J.

Agency: Defence and Civil Institute of Environmental Medicine,
Canada

Date: 1979

Hypothesis: Subjects voluntarily maintain an energy expenditure equivalent to 40% of the VO_2 max for as long as 6 days. Other factors may exist which limit performance under these conditions.

Stressors: The road march covered 204 km in 6 days. Distance covered each day ranged from 30 to 38.5 km/day. Load weights varied from 22.5 kg on the first day to weights selected for each subject such that at a walking speed of 6 km/hr, the energy expenditure was 40% of his VO_2 max. Subjects were given two 20 min stops in the morning and afternoon, and a 60 minute break for lunch.

Tasks: A road march of 204 km, completed in 6 days, with external loads.

Subjects: 25 French infantry soldiers, selected for high level of physical fitness and proficiency in athletics.

Results: Subjects marched a distance of 34 km at an average speed of 6 km/hr. Subjects did not maintain this rate for the remaining days and the energy costs were less than the prescribed 40% VO_2 max. Mean heart rates for the groups categorized by load weights (low, medium, heavy) were essentially the same for all three conditions, indicating that the energy expended by the three groups was nearly the same.

After the initial decline in walking speed, subjects maintained an average energy expenditure of 31.6% of VO_2 max, or 384 kcal/h for the remainder of the march. This energy expenditure is within the 425 kcal/h suggested as the "maximum hard work adopted voluntarily by physically fit young men." Fit young soldiers will continue to self pace at this level for 6.5 h per day for 6 days.

All of the injuries encountered during the exercise were due to foot disorders, such as blisters.

Critique: No mention is made of the amount of sleep allowed between days. As mentioned by the authors, training must be specific. Training adaptations are specific to the training methods. In addition to training in aerobic sports, more training time should have been devoted to marching on hard road surfaces with heavy loads to avoid the minor injuries and sore feet which seemed to be the main factor limiting the rate at which the platoon moved.

Document No: 395

Title: SLEEP LOSS EFFECTS ON CONTINUOUS SUSTAINED PERFORMANCE

Authors: Mullaney, Daniel J., Kripke, Daniel F., and Fleck, Paul

Agency: University of California (San Diego)

Date: 1981

Hypothesis: When absolutely continuous sustained work is required, performance will deteriorate seriously even within the first 24 hours, contrary to the results of many other sleep loss experiments.

Stressors: 42 hours of continuous attention-demanding work with only very brief breaks for obtaining something to eat or drink and to go to the restroom. (Two control groups received 6 hours of sleep during comparable 42 hour work schedules: (a) one received a block of 6 continuous hours of sleep after 18 hours on duty; and (b) the second received 6 one-hour rest periods equally spaced throughout the 42 hour performance period.

Tasks:

1. A 3-minute tracking task requiring the subject to use a joy stick to position a target to the exact center of a grid and then press a trigger in an effort to score a hit.
2. A 3-minute visual pattern memory test.
3. A 3-minute test of numerical addition skills
4. An auditory vigilance task presented simultaneously with tasks 1-3.

These tasks were administered repeatedly every 10 minutes throughout the period of performance testing, resulting in 6 scores per hour for each task (some time was also devoted to securing subjective estimates of fatigue). Task 1 was self-paced; Tasks 2 and 4 were experimenter paced; Task 3 was adaptive to the individual's ability but demanded maximal performance speed.

Subjects: 32 male volunteers, mostly university students.

Results: Subjects had marked difficulty in sustaining truly continuous performance for 42 hours. Performance on all tasks deteriorated and three subjects had to discontinue participation despite high motivation (motivation was established by a payment schedule that was directly tied to performance effectiveness). In general, when absolutely continuous sustained work was required, performance deteriorated seriously even within the first 24-hours. Many of the subjects who performed without rest periods experienced psychiatric symptoms such as hallucinations, visual illusions, and sensations of de-realization. These symptoms appeared much earlier than had been reported in sleep loss studies where only intermittent performance was required.

The totally sleep-deprived group performed more poorly on each of the tests than did those who received 6 hours of sleep. In general, 6 hours of block sleep resulted in better performance during the two 18-hour continuous work periods than did 6 1-hour naps. Subjects permitted 6 1-hour naps experienced a sleep "hangover" when engaged in their first performance test following the sleep period. Subjects who received 6 hours of sleep in either pattern suffered fewer psychiatric symptoms.

Critique: This is something of a landmark study in sleep deprivation research. The investigators' hypothesis that performance would degrade earlier and to a greater degree when performance is assessed more or less continuously was clearly supported. Even though performed in the laboratory, using classic laboratory tests, this study has important implications not only in regard to the extent of deterioration found on fundamental human processes, but it stands as a critique of all fatigue studies, whether performed in the laboratory or in the field, that have relied (as so many have) on short-term performance test procedures, widely spaced in time.

Document No: 494

Title: SUSTAINED OPERATIONS: RESEARCH RESULTS

Authors: Naitoh, P., Englund, C.E., and Ryman, D.H.

Agency: Naval Health Research Center, San Diego, CA

Date: 1987

Stressor: Simulated 5 day reconnaissance mission (SUSOP). Various continuous work and napping schedules were employed in a series of experiments conducted over a period of 7 years. Maximum continuous awake period in these experiments was 45 hours.

Tasks: Alpha-numeric visual vigilance task; reaction time tasks, logical reasoning, word memory. Subjects worked at computer video stations, responding to prompts for psychological tasks, physiological measures, etc. One-half of the subjects performed the vigilance task while walking a treadmill in full combat gear for the first 30 minutes of each hourly session. The other half of the subjects performed this task while seated at the work station. Treadmill speed was adjusted to keep heart rate at 30% of maximal aerobic power.

Subjects: A total of 112 U.S. Marine Corps volunteers in 13 groups

Results:

- (1) Starting time of a mission had major effects on performance (reaction time and vigilance) throughout the mission. It is stated that starting time should not be chosen so that a continuous work episode ends near the circadian trough in body temperature.
- (2) After the first 20 hours of continuous work, more than 3-4 hours of sleep is required to assure full recovery from fatigue. Allowing only 3-4 hours of sleep will result in a 30% degradation from baseline performance and increased fatigue during a second 20-hour continuous work episode
- (3) When subjects are required to do moderate physical work during continuous work episodes, performance, mood, and fatigue are affected to a greater extent than when no physical work is done
- (4) Physical workload of 30% of maximal aerobic power or greater will slow down response speed during a subsequent post physical work period
- (5) The circadian phasing of nap time is less important than the duration of the nap in determining the recuperative power of the nap. However, when awake time is extended beyond a period of 12 hours, the circadian phasing becomes more important. Under these conditions, a short nap taken during early hours (0400 - 0700) will be followed by profound and persistent sleep inertia (pp 2-3).

Document No: 413

Title: SLEEP MANAGEMENT IN SUSTAINED OPERATIONS USER'S GUIDE

Authors: Naitoh, P., Englund, C.E., and Ryman, D.H.

Agency: Naval Health Research Center, San Diego, CA

Date: 1986

Stressor: Sleep debt

Task: Not applicable. This is a guide for field commanders who are facing sustained operations. The contents include sections on work/rest-sleep and sleep loss problems during pre-deployment, deployment, pre-combat, combat and post-combat phases; ways in which sleep management copes with performance degradation caused by work/rest-sleep and sleep loss problems; identifying signs of the problem, and devising ways to overcome it.

A number of generalizations, based largely on experiments with military personnel, are made in the summary (pp 22-23). These are reproduced here:

- (1) Degrading effects of sleep loss on performance, moods, and willingness to work are felt most strongly during the daily circadian trough, as defined by body temperature. The circadian trough occurs between 0200 and 0600 of the time zone to which the body is adapted.
- (2) There is a significant loss of performance efficiency when a SUSOP demands a longer than 24-hour continuous work episode (CWE). After a CWE of 36-hour duration, target detection is 70% and decoding is 50% of baseline.
- (3) Uninteresting and complex tasks are more seriously affected by sleep loss than interesting and/or simple tasks.
- (4) Critical but routine tasks are often skipped because sleep loss reduces overall willingness to respond.
- (5) Physical work feels much heavier than it did before sleep loss because of exaggerated perception of physical exertion.
- (6) Short-term memory is seriously affected. Poor short-term memory and lapses in attention work against effective communication. Sleep loss causes a listener to forget what was recently said in a conversation. A listener may fill the information gap by inaccurately restructuring the conversation.
- (7) The ability to initiate action decreases with increasing sleep debt. This decrease in initiative includes all interactions among team members.

- (8) Sleep-deprived individuals tend to overestimate their ability to do tasks. That is, they lose insight as to how well they are performing their assigned tasks.
- (9) Sleep loss causes deterioration of personal hygiene, such as keeping the feet clean and dry.

Document No: 161

Title: PERFORMANCE, MOOD, AND CLINICAL SYMPTOMS IN MEN EXPOSED TO PROLONGED, SEVERE PHYSICAL WORK AND SLEEP DEPRIVATION.

Authors: Opstad, Per Kristian, Ekanger, Roald, Nummestad, Morton, and Raabe, Niles

Agency: Norwegian Defense Research Establishment, Institute of Work Physiology, and Norwegian Military Academy

Date: 1978

Hypotheses: Prolonged, severe physical work combined with sleep deprivation will adversely effect various psychological functions and tasks associated with the performance of soldiers.

Stressors: 4 or 5 day Ranger training course with either no organized sleep, 3 hours sleep, or 6 hours sleep in the middle of the course. Except for testing periods, the subjects engaged in heavy physical work associated with Ranger training, as well as caloric deficit.

Tasks: Visual vigilance test, self paced reaction time task, a coding test, visual acuity, motor coordination, speed of association, a sorting test of ability to react to three auditory impulses given simultaneously by doing a relatively complicated manual task; a shooting task requiring the subjects to fire, change magazines, fire, change magazines, and fire again at a target 35 cm in diameter at a distance of 25 meters (grouping capacity was assessed); and a command memory task requiring the memorization of a standard military message which had to be recalled and reproduced about one hour after a particularly strenuous physical task was performed.

Subjects: 44 cadets of the Royal Norwegian Military Academy

Results: Substantial impairment was observed in all of the tests. Clinical symptoms appeared at the end of the course in those subjects who had no organized sleep. Significant impairment was observed even after 24 hours in the vigilance test, the reaction time test, and the code test, as well as in subjective state.

The group receiving 6 hours did significantly better than the no sleep group on all tests, and the group receiving 3 hours sleep occupied an intermediate position.

In the shooting task there were no differences in the time taken to perform the task and in grouping scores for subjects receiving sleep but no-sleep subjects dropped to 90% of baseline. Schedules did not permit the testing of subjects on the last day of the course when the greatest degradation appeared on all other tests. The command memory task showed considerable performance degradation, particularly for the no sleep groups; again, it did not prove possible to administer this test on the last day of the experiment.

Critique: This is one of a relatively small number of studies in which physical fatigue stress was combined with sleep deprivation stress. The debilitating effects on psychological functions are clear. Unfortunately it is not possible to separate the sleep loss effects from the physical fatigue effects since there was no control group with normal sleep.

Document No: 567

Title: PREDICTING ENERGY EXPENDITURE WITH LOADS WHILE STANDING OR WALKING VERY SLOWLY

Authors: Pandolf, K. B., Givoni, B., and Goldman, R. F.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1977

Hypothesis: Studies of walking at very slow speeds and of standing with backpack loads were performed to determine the effect of body weight and slow speed walking and the dynamics of the load.

Stressors: Walk with 3 loads (30, 40 and 50kg) at 5 different speeds (.2, .4, .6, .8, and 1.0 m/sec), over a level terrain. Prolonged stand with 0, 10, 30 or 50 kg backpack was also investigated.

Tasks: Walk with load at slow speeds. Walking was done on the floor, with 15 speed/load combinations.

Subjects: Six fit, adult male subjects in the walking study; 10 different male subjects in the standing study.

Results: Energy expenditure increased with external load, both standing and walking. No increased inefficiency occurred with very slow walking. Metabolic rate decreased smoothly as speed approached zero.

The revised predictive formula which now covers standing and the whole range of walking speeds is as follows:

$$M=1.5W+2.0(W+L)(L/W)^2+n(W+L)[1.5V^2+0.35VG]$$

where

M = metabolic rate, in watts

W = subject weight, kg

L = load carried, kg

V = speed of walking, m/sec

G = grade, in percent

n = terrain factor (n=1.0 for treadmill)

The predictive formula was developed for backpack loads only.

Simply standing with packs constitutes an entirely different work mode, static work, which involves primarily tension in muscles used for maintenance of the load. No mechanical work is done as in walking, but maintaining tension does require energy.

Difficult terrains seem to necessitate a combination of greater muscle mass usage, added lift (static) work, and a forward stooping posture with the associated increased energy demands.

Document No: 536

Title: PREDICTION MODELING OF PHYSIOLOGICAL RESPONSES AND HUMAN PERFORMANCE IN THE HEAT

Authors: Pandolf K., Stroschein L., Drolet, L., Gonzalez, R., and Sawka, M.

Agency: US Army Research Institute of Environmental Medicine, Natick, MA

Date: 1986

Hypothesis: Based on an empirically derived database, it is possible to develop a series of predictive equations for deep body temperature, heart rate, and sweat loss responses of clothed subjects.

Stressors: Program considers physical work intensity, environmental conditions, and particular clothing ensemble, as well as energy expenditure, state of heat acclimation, and solar heat load.

Tasks: Physical work in a variety of environmental extremes.

Subjects: A range of military subjects, culled from numerous studies.

Results: Specific prediction equations are provided for final equilibrium rectal temperature (suggested by Givoni and Goldman), composed of a series of equations to predict each of three components:

metabolic,
dry heat exchange, and
evaporative heat exchange component.

Work rest cycles were computed from an analysis of patterns of rectal temperature over three different conditions:

- (1) the time pattern for resting subjects under various heat stress conditions;
- (2) the elevation pattern for rectal temperature during physical work at given climatic conditions; and
- (3) the recovery rectal temperature after cessation of physical work.

Prediction equations were also provided for sweat loss and final equilibrium heart rate.

The model has been programmed on an HP 41CV. Model input includes selections from clothing menus (25 systems are available, including 4 levels of MOPP gear); metabolic work rates (light to heavy) or derived from body weight, external load, walking speed, and terrain coefficient; casualty rates, acclimatization states; air temperature; relative humidity; wind speed; and solar load.

Output includes the calculated work-rest cycle, the one time only maximum work period, the water requirements during work, rest, and combined.

Document No: 538

Title: A COMPARISON OF THE EFFECTS OF MIXED STATIC AND DYNAMIC WORK WITH MAINLY DYNAMIC WORK IN HOT CONDITIONS

Author: Randle, I., and Legg, S.

Agency: Army Personnel Research Establishment, Farnborough, UK

Date: 1985

Hypothesis: Work containing a high proportion of static effort is more fatiguing than mainly dynamic work. The study makes a direct comparison of the effects of mainly dynamic work (e.g., walking on a treadmill) with mixed static and dynamic work which would represent a realistic task).

Stressors: The study compares the metabolic, cardiovascular, thermal, and subjective responses to static and dynamic work in hot conditions. External work output were equivalent in both static and dynamic work, set to around 500 W, or 7 kcal/min. The mean measured climate WBGT conditions were 32.8 degrees C, dry bulb, 24.7 degrees C wet bulb, 60% relative humidity.

Walking was at a set pace on a graded treadmill. Carrying involved walking on the treadmill while holding a 20 kg box in front of the body every 30 seconds out of 60 seconds. Duration was 1 hour, or less if the subjects heart rate or temperature exceeded threshold.

Tasks: Two tasks were studied: steady uninterrupted uphill walking, and an uphill walk while intermittently carrying a 20 kg weight in the arms.

Subjects: Eight soldiers, physically fit, and unacclimatized at the time of the experiment.

Results: All subjects completed the one hour walk without load, but none could carry for the hour without exceeding one of the withdrawal criteria.

Oxygen consumption, minute ventilation, sweat rate and rated perceived exertion were all significantly higher for the mixed static and dynamic work than for the dynamic work. Similarly, heart rate and internal temperature were also higher.

For the same external work, physiological strain and perceived exertion were greater for mixed static and dynamic work than for mainly dynamic work.

Critique: The differences in perceived exertion and physiological strains between mixed and purely dynamic work suggests that it is not appropriate to make direct comparisons of laboratory studies based on dynamic work, with practical situations containing mixed static and dynamic work in the heat. The need for a consideration of the nature of the work as well as its magnitude is thus highlighted.

Document No: 337

Title: FACTORS INFLUENCING THE SUSTAINED PERFORMANCE CAPABILITIES OF 155 MM HOWITZER SELECTION IN SIMULATED CONVENTIONAL AND CHEMICAL WARFARE ENVIRONMENTS

Authors: Rausch, T.M., Banderet, L.E., Tharion, W.J., Munro, I., Lussier, A.R., and Shukitt, B.

Agency: U.S. Army Research Institute of Environmental Medicine, Natick, MA

Date: 1986

Stressors: 24 hours of sustained operations, wearing MOPP gear in high ambient temperatures (average daytime temperature 95 degrees F).

Subjects: Four howitzer sections, of 9 men each.

Results: The procedure required the teams to engage in 24 hour live fire scenarios during which selected tasks from the Army Training and Evaluation Program (ARTEP) were performed. Five missions were received from a Fire Direction Center. The authors conclude that their findings support previous research in that psychological fatigue rather than perceptions of muscular fatigue are the primary problems affecting sustained artillery performance in conventional warfare environments.

Artillery tasks performed in MOPP IV gear during average daylight temperature produced intense symptoms associated with respiratory distress and heat illness: "short of breath" "hard to breath", "headache", "fatigue", and "dizzy".

First round firing times after receipt of the fire mission quadrant, showed a 74-163% increase in time required to perform in the early morning hours compared to the previous afternoon hours. Inter round intervals were also the greatest between 0020 and 0720 hours. It was concluded from the psychological data that the period between 0100 and 0700 hours represented the interval when the soldiers experienced the greatest decrement in clear thinking and concentration, as well as the highest state of nervousness. The degradation in psychological state was correlated with the decrement in artillery performance observed during these hours.

Document No.: 596

Title: PERCEIVED EXERTION UNDER CONDITIONS OF SUSTAINED WORK AND SLEEP LOSS

Authors: Rayman, D.H., Naitoh, P., and Englund, C.E.

Agency: Naval Health Research Center

Date: 1987

Hypothesis: The study documented the changes in Rated Perceived Exertion (RPE) during both repeated maximal and submaximal exercise over a 40 hour period of intermittent exercise with accompanying sleep loss, and determined if and when the relationships of RPE and workload level, heart rate, and psychological measures exist.

Stressors: In study 1, two groups repeatedly exercised (treadmill walking) at 40% of VO_2 max while carrying a 22kg pack. Group 1 took a 4 hr nap between the two days of continuous work.

Study 2 used a constant 30% of VO_2 max exercise level over the two days with Group 3 starting exercise at midnight and Group 4 starting at 1300.

Maximal stress tests were performed on day 1. Subjects were also trained and tested on the psychological questionnaire and the various vigilance tasks they would perform during testing. Vigilance tasks were performed during rest periods for the control group, and while undergoing submaximal treadmill exercise by the experimental group.

Levels of exertion were maintained until a subject felt he could no longer complete a half hour exercise session. Subsequently, treadmill grade and then speed were reduced as necessary. Tests were stopped due to leg cramps or leg fatigue, breathing difficulty, complete exhaustion, and/or others.

Tasks: Subjects walked for 17 one-half hour sessions on each of two consecutive days (34 sessions overall). Subjects also performed vigilance tasks on a computer terminal.

Subjects: 37 healthy US Marine Corps volunteer, enlisted personnel.

Results: RPE measures were recorded half way through each exercise session. Heart rate and treadmill speed and elevation were averaged over the entire session. Fatigue, mood, symptoms and sleepiness were measured immediately after each session.

There was a significant linear increase in RPE over the sessions during each day and a significant drop in RPE from the last session of continuous work (day 1) to the first session of continuous work on day 2. There was no difference between nap or rest conditions or midnight vs noon start times in terms of RPE.

With higher levels of exercise (Study 1, 40% VO_2 max) RPE was more strongly related to HR and workload measures than during low levels of exercise (Study 2, 30% VO_2 max). The psychological measures (fatigue, vigor, sleepiness) showed stronger and more persistent relationships with RPE at lower levels of exercise. The RPE after continued, repeated exercise of more than one day does not seem to reflect workload, physiological responses, or psychological perceptions of fatigue or sleep.

Document No: 417

Title: ALERTNESS, FATIGUE AND MORALE OF AIR FORCE SENTRIES

Authors: Sanford, James F., Steinkarchner, Raymond E., Cantrell, George K., Trimble, Ralph W., and Hartman, Bryce O.

Agency: USAF School of Aviation Medicine, Brooks Air Force Base, Texas

Date: 1971

Stressors: Exposure to danger of enemy action in Southeast Asia. Fatigue resulting from guard duty in a combat environment, measured subjectively. Nighttime duty. 8-hour sentry tours.

Task: Detection of randomly illuminated lights. Six lights were placed in a quadrant of a circle approximately 50 feet from the airplane or missile being guarded.

Subjects: U.S. Air Force sentries; the number varied from 49 to 64 in different studies. Some were studied at CONUS bases; others in Southeast Asia.

Results: In CONUS, the sentries showed a progressive increase in feelings of fatigue across 8 duty hours without a corresponding measurable loss in alertness (response time to illumination of a light). In SEA, there was a substantial increase in response time to the signal lights with increase in duty hours for each of several groups of sentries studied. In general, the average response time was about 5 secs during the first hour of the vigil and increased to 12-13 seconds during the 7th hour. The data for several sentries who did not respond after 60 seconds were excluded from the analysis. Subjective fatigue ratings followed a corresponding increasing trend. No consistent relationship was shown between amount of sleep prior to sentry duty and subjective ratings of fatigue.

Critique: No adequate measures of possible cumulative sleep loss were collected, nor was there any documentation of other activities that, in a combat zone, could have led to differential fatigue. Rather, the authors attribute differences in results between SEA and CONUS to morale differences. In CONUS, the absence of a decline in response time could well reflect the alerting effect of the experimental procedure in an otherwise dull, tedious period of watch.

Document No: 181

**Title: HUMAN PERFORMANCE IN CONTINUOUS OPERATIONS: VOLUME III
TECHNICAL DOCUMENTATION**

Authors: Siegel, Arthur I., Pfeiffer, Mark G., Kopstein, Felix,
Wolf, J. Jay, and Ozkaptan, Halim

Agency: U.S. Army Research Institute for the Behavioral and Social
Sciences

Date: 1980

Hypothesis: Not applicable. This volume documents the technical procedures used to analyze the adverse effects of continuous operations on human performance and to project diminished performance capabilities as a function of time.

Tasks: The document contains detailed listings of tasks associated with mechanized infantry, including those performed by vehicle drivers, gunners/carrier team leaders, infantry maneuver team members, squad leaders, platoon leaders, tank platoon leaders, commanders, tank gunners, tank loaders, tank drivers, FIST chief, observers, support NCOs, radio telephone operators, artillery battery executive officers, howitzer section chiefs, gunners, and crew members.

Subjects: Not applicable. The document is intended to apply to mechanized infantry personnel, FIST personnel, tank crews, and artillery battery personnel.

Results: This report presents and projects estimates of performance effectiveness at the squad, platoon, and company level, and suggests the effects of task restructuring on effectiveness. It contains results of a survey of the literature concerning the effects of continuous operations on military performance; describes methods for deriving "critical tasks"; describes the mathematical procedures employed to calculate projected performance effectiveness; describes a computer simulation model, which incorporates human effects, for simulating human performance in continuous operations.

Estimates are reported of task utility (importance), how ratings of this variable were derived, and the method of aggregation of criticality values. This involved deriving the utility of each task relative to general mission goals associated with a mid-European combat scenario involving combined arms team operations, continuous day/night battle extending over a period of 5 days, periods of rain and limited visibility, initial adversary manpower superiority of 6 to 1, and non use of nuclear capability. The contribution of each task to mission success was estimated by the program's technical military consultant (N-1). A similar rating technique also involving the estimates of a single individual was used to rate the importance of various platoon action goals in accomplishing the general mission goals.

A task was identified as "critical" if it had a "high" aggregate utility rating in regard to general mission goals and on at least one of three sets of specific platoon action goals. The number of "critical" tasks performed by each classification of mechanized personnel was subsequently determined. For example, of 58 critical tasks divided across four positions among personnel in tanks (out of a total of 218 tank crew tasks) it was concluded that the tank driver is not responsible for any critical tasks.

An assessment was made next of the degree of impact of continuous operations on each of the critical tasks. This assessment was made by two psychologists and a military expert, reportedly making use of data, graphs, curves, tables and so forth in the literature, to determine whether a "significant depressive effect would be manifested". "Significant" was defined as the likely shrinkage in the ability in question by 20%. Each judge worked independently initially, and a consensus was later established. It was stated (page 53) that the scientific literature produced sufficient information to make well supported judgements as to the various impacts on abilities, (but) the information was not adequate to support the judgements as to interactions among debilitating factors, among critical abilities, or across both.

The authors state (pages 54-55) that "there is unanimity in the scientific literature that the full debilitating effects of sleep loss take place between the 36th and 48th hour of continuous wakefulness." The effect is aggravated with further sleep deprivation. Moreover, for some cognitive functioning, the effects begin to manifest themselves after as little as 24 hours without sleep. This argument is used in describing the "progressive degradation function (E) which represents the "joint and full impact of the applicable, adverse or debilitating factors." E_i is the projected effectiveness of performance on the i -th day. A value of E is calculated which reflects performance of each specific task. The effectiveness of a given duty position is calculated as equivalent to the value of E compounded across the corresponding sets of tasks. The value of E is also calculated for specific tasks occurring within different types of defensive (platoon) actions (page 55).

A model reflecting these kinds of estimations is described in Chapter 4. The model is named "PERFECT" for Performance Effectiveness of Combat Troops. The psychological condition of the troops is a primary variable in the model, and this variable is reflected in a representation called "stress". The simulation model is based on a series of manipulations of a four dimensional effectiveness matrix as a function of the composition of the combat force, the mission sequence designated, and parameter input values (page 63). In general, effectiveness levels will degrade as a function of time, but improve with sleep and rest. Effectiveness also degrades with increasing stress level of the troops. The latter is a function of light level conditions, terrain advantage, squad proficiency level, enemy/friendly personnel strength ratio, friendly vulnerability, and enemy/friendly material strength ratio. Effectiveness also improves, (i.e., is restored) when platooning is specified to replace designated combat units (page 64).

The model incorporates stress buildup via battle condition, and stress relief via sleep. It accommodates continuous operations durations up to 5 days. It will consider a maximum of 16 duty positions and 9 unit types. How the "current value of the stress" is derived is described on page 79.

Critique: This document incorporates numerous extrapolations from data in the scientific literature, numerous estimates regarding task performance by Army personnel, and numerous assumptions about the effects of variables making up "stress". It merits careful scrutiny because it is apparently the basis for currently published estimations of performance degradation for various classes of mechanized Army personnel engaged in continuous operations.

Document No: 110

Title: HUMAN PERFORMANCE IN CONTINUOUS OPERATIONS: VOLUME I. HUMAN PERFORMANCE GUIDELINES

Authors: Siegel, Arthur I., Pfaiffer, Mark G., Kopstein, Felix, and Wilson, Lawrence G.; also Ozkaptan, Halim (ARI)

Agency: U.S. Army Research Institute for the Behavioral and Social Sciences

Date: 1979

Hypothesis: Not applicable. This report provides guidelines to the military commander on expected human performance degradation associated with continuous ground combat. Degradation projections are based on extrapolations from scientific literature and "realistic scenarios of continuous operations".

Stressors: Fatigue, stress (defined in Volume III, see Document No. 181) performing in low light levels and/or with poor visibility, diurnal rhythms.

Tasks: 58 "critical" tasks associated with mechanized infantry performance, tank crew performance, fire support team performance, and artillery battery performance.

Subjects: Not applicable. The results and recommendations are intended to apply to all mechanized infantry personnel, tank crews, fire support teams, and artillery battery teams.

Results: Projected performance degradation curves are presented showing "effectiveness" after 24, 48, 72, 96, and 120 hours of continuous operations. These functions are shown separately for different personnel (e.g., tank platoon leader, tank commander, tank gunner, tank leader) reflecting the predicted differential impact on the different types of tasks these personnel perform. For each critical task various "critical abilities" e.g., numerical facility, perceptual speed, orientation, vision, communication) are judged to be associated with that task, which in turn are affected by "adverse factors" such as fatigue, diurnal rhythm, low light level/visibility, and stress. (For example see page 265).

Critique: Since the projections in this document appear to go well beyond the data in available, relevant literature, careful examination must be made of the assumptions and methods of procedure used in making these projections. (See Siegel et al., 1980).

Document No: 558

Title: PACING OF INTERMITTENT WORK DURING 31 HOURS

Authors: Soule, R. G., and Goldman, R. F.

Date: 1973

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Hypothesis: The perceived level of difficulty increases with continuous operations without sleep, thus leading to voluntary hard work to be paced at a lower energy cost level.

Stressors: Subjects did not sleep during each of two separate 31 hour test periods. External loads were 15 kg and 30 kg respectively, on the two test schedules. March duration was for 4.8 km or 1 hour, whichever came first, repeated 6 times during the 31 hours. Subjects were not allowed to rest during the intervening 5 hour periods. March rate on the treadmill was self-paced.

Tasks: Walk 4.8 km on a treadmill during 1 hour, six times in one period, carrying loads.

Subjects: Six subjects (completed the study).

Results: With the 15 kg load, walking rates increased at hour 7 and 13 into the study, compared to hour 25. No differences existed for the heavier 30 kg load.

The relationship between heart rate and reported perceived exertion level was not significant. There was clearly a progressive increase in the perceived exertion level reported for both loads, but the differences were not significant.

Based on the average time to walk each 400 m, the distance completed and the heart rates, it appears that man will continue to voluntarily work at a pace that will result in a predictable voluntary hard work level of approximately 7 kcal/min even when forced to stay awake for 31 hours.

It appears that an extended 31 hour operation, without sleep, is not sufficient to measurably change the voluntarily selected "hard work" rate. However, the subjective evaluation of perceived exertion level may very well increase despite constant work and physiological responses.

Critique: The difference between the treadmill walking tasks and the sedentary activity performed during the balance of the test period is worth considering. The 5 hours of rest during sedentary activity, may well be sufficient to overcome any fatigue brought on by the exertions. Results regarding perceived discomfort may also be confounded with discomfort arising from the weight of the pack on the shoulders.

Document No: 542

Title: VOLUNTARY MARCH RATE AS A MEASURE OF WORK OUTPUT IN THE HEAT

Authors: Soule, R., and Goldman, R.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1978

Hypothesis: Determine whether men, trained to adopt a march rate which would complete an 8 km march in 120 min or less under one set of environmental heat stress conditions, would march at a similar rate under more severe and also under less rigorous conditions.

Stressors: Temperature remained fixed at 40 degrees C, relative humidity varied from 25% to 75%.

Test period totaled 120 minutes, with 55 minute continuous walk.

Tasks: Simulated 8 km march on a self-paced treadmill with 10 or 18kg backpack.

Subjects: 13 soldiers, acclimatized to 40 degrees C, 50% relative humidity, and trained on the procedures.

Results: Subjects tended to walk at the same pace that they had adopted under the training or acclimatization conditions. Although a generalized trend for slowing the adopted march rate with increasing humidities can be observed, the times to walk each 1.6 km of a maximum 8 km march did not differ significantly under the various conditions, except for the most severe condition (75% relative humidity). Although physiological cues of heat stress must have been present, the subjects appeared to ignore them and even under the most severe humidity conditions continued to walk at a pace contributing to heat exhaustion.

Document No: 392

Title: PLUMBING HUMAN PERFORMANCE LIMITS DURING 72 HOURS OF HIGH TASK LOAD.

Authors: Thorne, D., Genser, S., Sing, H., and Hegge, F.

Agency: Walter Reed Army Institute of Research

Date: 1983

Hypotheses: Under conditions where sustained individual cognitive performance is required, different cognitive functions assumed to have importance in command, communications, and control will progressively degrade as a function of time.

Stressors: 72 hours of continuous performance and enforced wakefulness. Initially, 30 minutes of each hour were spent in performance testing with the remainder of the hour free for a wide variety of leisure activities, but not sleeping. As the study progressed, because of the reduced speed of the subjects' performance, a larger portion of each hour was spent performing the tests with commensurately less time available for leisure activities.

Tasks:

1. 2 and 6 letter search tasks, requiring visual search and recognition.
2. 2 column addition (subject paced).
3. Logical reasoning.
4. Digit recall, a test of short term memory capacity.
5. Serial addition/subtraction.
6. Pattern recognition 1 and 2, spatial memory tasks at two levels of difficulty.
7. Lexical decision task.
8. Vigilance and detection task

These tasks were grouped into two "packages" for test administration purposes along with other measures such as mood-activation scale, illusion scale, and fatigue checklist. As noted, each package could be administered in 30 minutes but, as the study progressed, subjects found it increasingly difficult to complete the tests in that amount of time. The original "50% duty cycle" gradually progressed to about 70% with occasional excursions to a full 100% duty cycle.

Subjects: 2 female and 6 male volunteers, ranging in age from 18 to 21. All were high school graduates and most had some college.

Results: 72 hours of sleep deprivation produced a moderate and continuous reduction in accuracy and a much larger increase in reaction times for all subjects on all tests in the performance battery. The authors used a measure of "throughput" which numerically is equal to the number of correct responses, divided by cumulative reaction time. This provided a convenient common metric for comparing results on very dissimilar tests. Averaged over all 8 tasks, throughput declined 74% from baseline over the 72 hour period. The pattern and magnitude of decline in throughput was similar across all tasks. This result, which was not anticipated, may represent a general psychophysiological effect of sleep deprivation according to the authors.

Relative throughput values averaged across all tasks also revealed a cyclical circadian variation with an amplitude of approximately 10% of baseline value, which was superimposed on the monotonic negatively accelerated downward function.

Viewed over the entire experiment, throughput dropped approximately 1% per hour or about 24% per day.

A four hour nap at the end of the 72 hour period produced marked improvements in all objective and subjective measures, but overall performance was still about 25% below baseline.

All subjects experienced perceptual distortions and visual hallucinations. They were reported as early as 24 and as late as 64 hours after start of the experiment. Some subjects were disturbed by them and at least one considered them to be real. The authors speculated that if such hallucinations were to occur under field settings without advance information, it could cause morale problems and/or further exacerbate performance decrements. If such hallucinations were acted upon as if they were real, the consequences could be serious.

Critique: This study employed a superior experimental design and methods of analysis. Coupled with the work of Mullaney, et al. (1981) and Angus and Heslegrave (1985) this work provides one of the more provocative insights into the kinds of problems that may be encountered when soldiers are engaged in truly continuous operations for many hours at a time. It further brings into question those studies that have employed periodic short tests of performance spaced at comparatively long intervals between testing periods. It is a key study in that it clearly shows that a diversity of human cognitive functions suffer very similar performance degradations, as well as cyclic variations, when a meaningful, common performance metric is employed.

Document No: 595

Title: DEVELOPMENT OF A SOLDIER LOAD ASSESSMENT METHODOLOGY

Authors: Wagner, M., and Kunz, E.

Agency: Dynamics Research Corporation for US Army Research Institute
for the Behavioral and Social Sciences

Date: 1986

Hypothesis: A systems approach can be applied to addressing a single deficiency identified by the Close Combat (Light) Mission Area Analysis: the inability of the individual dismounted soldier to carry his combat load. The resulting model is to serve as a framework for monitoring the extent of the problem.

Stressors: The constraints that cause the load carrying deficiency, particularly the physical limitations of the soldier.

The models and tasks used in developing the approach were based extensively on the work out of the US Army Research Institute of Environmental Medicine at Natick, Mass. Published work by Goldman, Legg, Soule, Patton, and others laid the groundwork for predicting workload based on a number of environmental, subject, and task variables.

Key factors which influence the physical work required, and which are included in the assessment include:

- the weight of the load
- the distance over which the load must be carried
- march rate for advancing
- quality of footing on the terrain being crossed
- grade of the march route,
- and the weight of the soldier who carries the load.

Soldier load consists of the total combat and sustainment load a soldier must carry. This combat load consists of three parts: a light fighting load, an assault pack, and a rucksack. The first must be carried at all times; the remaining may be carried, or supplied via other means.

Rate of march is the single largest determinant of the physical demands being made on the infantry soldier. Faster march rates lead to a higher demand. The upper limit for walking is considered to be 5.3 mph. At greater speeds, running becomes more efficient.

Positive percent of grade requires dramatically higher levels of effort than marching over level terrain.

Terrain also influences the physical work required to march. Various terrains have been associated with empirically established footing factors which proportionally represent the relative effort required to march at a specified rate.

The weight of the soldier affects the amount of physical work required to carry a load. For equally fit soldiers, however, a heavier soldier will also have a greater capacity to perform physical work than a lighter soldier.

Tasks: Carrying heavy loads by foot-mobile soldiers into combat. Several low- and mid-intensity scenarios were used to develop mission load requirements and to determine the requirements for troop movements.

Subjects: Model based on numerous studies, generally performed on military subjects.

Results (from report, section 5): The five variables described above were incorporated into a quantitative model that produces a measure of the physical workload required to carry a load in a given scenario. The measure of physical workload selected for this analysis is metabolic cost. Metabolic cost represents the aerobic energy that must be expended by a soldier to march, carry a load, and perform other soldiering tasks during a scenario.

The metabolic cost model used in this study (Pandolf, Givoni, and Goldman, 1977) is shown below:

$$M^* = \frac{1.5W + 2.0(W + L) \left(\frac{L}{W}\right)^2 + N(W + L) (1.5V^2 + 0.35VG)}{1.1631}$$

where

M^* = metabolic cost (kcal/hour). Original formula expressed M in terms of watts. Formula was modified to express the energy expenditure in terms of Kilocalories (kcal) rather than watts. Kilocalories are equivalent to the large calorie which is used to express the heat- or energy-producing value in food when oxidized in the body.

W = subject weight, nude (kg)

L = external load (kg)

N = footing factor

V = velocity (meters/second)

G = grade or slope (percentage)

The formula for metabolic cost of load carrying consists of three components. The first component ($1.5W$) represents the base metabolic rate associated with standing without a load. Using the average weight of an infantry soldier, 160 lb or 72.58 kg, the baseline metabolic rate calculated for infantry soldiers is approximately 94 kcal/hour.

The second component of the metabolic cost formula ($2.0(W+L) (L/W)^2$) represents the incremental metabolic costs associated with the load borne by the soldier. With no load, this component equals zero. As the load increases to 100% of body weight, the incremental metabolic costs increase to 250 kcal/hour.

The third component of the formula $(N(W+L) (1.5V^2 + 0.35VG))$ represents the incremental metabolic costs associated with increased velocity, increased grade, and terrain with degraded footing. Velocity is treated as an independent contributor to metabolic costs as well as a contributor to the incremental costs associated with increased terrain grade.

Highly demanding scenarios can be constructed that far exceed the ability of even the most hardy infantry soldiers. The key question is where to draw the line between marches with loads that can be managed and marches that exceed the capabilities of well trained infantry soldiers.

To assist in applying the model, a set of tables was developed that could be used to compute the energy requirements associated with a particular scenario. Once the hourly metabolic costs of a scenario are determined, the ability of an infantry soldier to perform the mission can be assessed.

Critique: The report itself does not present anything new - but rather repackages an existing model for unit commanders to provide them with a tactical planning tool. It is useful when considering long marches over a range of terrain and conditions.

While a "fatigued" state is indicated by the resulting metabolic rate, the model will not provide a rate of fatigue over a timeline, something which would be of use to combat modelers.

Document No: 472

Title: HUMAN PERFORMANCE AND MILITARY CAPABILITY IN CONTINUOUS OPERATIONS: A USER-ORIENTED REVIEW OF THE LITERATURE ON THE EFFECTS OF SLEEP LOSS, WORK-REST SCHEDULES, AND RECOVERY OF PERFORMANCE

Authors: Woodward, Donald P., and Nelson, Paul D.

Agency: Subgroup U, Technical Cooperation Program (Australia, Canada, U.K., USA)

Date: 1974

Stressors: Continuous operations

Subjects: N/A. This was a review of the state of research knowledge on human performance capabilities and sleep loss.

Results: Since this was a review study, no research data were presented. However, a number of potentially useful generalizations were presented in tabular form. These are reproduced below (pp B-1 through B-4).

Tasks Most Vulnerable to Sleep-Loss Effects

- o Uninteresting and monotonous tasks
- o Tasks that are new or require learning on the job
- o Work-paced tasks (as opposed to self-paced tasks)
- o High-workload tasks that require time-sharing with other primary and secondary tasks
- o Tasks that require continuous attention and steady performance
- o Tasks in which the worker has little feedback on his performance

Work Schedules Most Vulnerable to Performance Impairment

- o Continuous, uninterrupted time on task for several hours duration
- o Work period between 0200-0600 hours (unless worker is specially prepared)
- o Night-shift work with worker having had less than three to five days on the night shift
- o Day and night shifts rotating on consecutive days
- o Work periods of around the clock with 2-hour rest intervals
- o First postsleep work period immediately following continuous duty

Amount of Sleep Loss Required to Impair Performance

- o 24 hours on routine and monotonous tasks or new skills
- o 36-48 hours on most tasks involving cognitive and perceptual skills
- o 50 per cent/24 hours cumulative reduction of normal sleep time over one week
- o 4-6 hours if working 0200-0600 watch after day of continuous work
- o 24 hours if sleep loss is imposed on one week of "4 on - 2 off" work-rest schedule
- o 24 hours if sleep loss is imposed on two weeks of "4 on - 4 off" work-rest schedule

Types of Performance Impairment Most Likely from Sleep Loss

- o Slower reaction time, increased time to perform known tasks
- o Short-term memory decrement, impairment in speed of learning
- o Impairment in reasoning and complex decision chain
- o Errors of omission, lapses of attention
- o Increased feelings of fatigue, irritability, depression
- o Erratic performance or increased variability in proficiency

Procedures for Reducing Performance Impairment Risks in Continuous Operations

- o Periodic breaks in task and mild physical exercise or recreation
- o 6-8 hours continuous off duty time per 24 hour period
- o Task rotation among cross-trained crew on relatively routine jobs
- o Task rotation among crew on complex tasks only when members are highly trained to shift functions
- o Selection of personnel who prefer and are able to adapt to different work schedules
- o Training on complex tasks to degree of "over learning"
- o System design to compensate for types of errors most likely to occur

Unusual Work Schedules: Time Required for Recovery and Adjustments

- o 12 hours sleep/rest before prolonged work period
- o 12 hours sleep/rest after 36-48 hours acute sleep loss (subjective fatigue may linger for three days)
- o 24 hours sleep/rest after 36-48 hours sleep loss with high work load (12-16 hours per day)
- o Two to three days time off after 72 hours or more acute sleep loss
- o Three to five days to initiate biological adaptation and return to normal day/night cycle from night shift work
- o Three to four weeks for full adaptation of biological rhythms to atypical work-rest schedules (as in night shift work)

APPENDIX B
ABBREVIATED SYNOPSES OF RELEVANT REPORTS

Document No: 466

Title: DEGRADATION OF TANK EFFECTIVENESS (REPORT DISTRIBUTION LIMITED)

Authors: Barron, R.C., Havens, J.W., Walters, R.F., Lutz, W.G., Talley, J.W., Degelo, G.J. and Smith, J.R.

Agency: Headquarters, TRADOC Combined Arms Test Activity, Ft. Hood, Texas

Date: 1976

Stressor: Tank operations, with hatch closed vs. open, day and night

Tasks: Target acquisition, live-fire, navigation

Subjects: 20 tank crews

Results: This study is only of peripheral interest to this review. Generally, crew performance was significantly poorer with the hatch closed than with it open. The reasons given relate primarily to system design, procedural and training issues. It might be expected, however, that crew fatigue and sleep deficit would make these problems worse in closed-hatch operations.

Document No: 525

Title: DURATIONS OF SAFE EXPOSURE FOR MEN AT WORK IN HIGH TEMPERATURE ENVIRONMENTS

Authors: Bell, C. R., and Crowder, M. J.

Agency: London School of Hygiene and Tropical Medicine, Medical Research Council Environmental Physiology Unit

Date: 1971

Stressors: Subjects were exposed to humid high temperature environments and to a range of relatively dry high temperature environments. Environmental conditions ranged from 37.0 to 30.0 degrees C dry bulb/wet bulb temperature in which air movement was either 0.76m/s or 1.02 m/s and air and wall temperatures were equivalent. Range represents environments which could be entered without special protective clothing and in which the duration of exposure would not be determined by intolerable pain or tissue damage in exposed skin surfaces. The desired minimum safe exposure time was set at 10 minutes such that sufficient time should be available to workers to perform useful work.

Tasks: Subjects performed a routine of continuous work on a stool-stepping task which required subjects to step on and off a 22.9 cm high stool in time with a signal light flashing at a rate of 12 times per minute. Subjects worked at roughly 4.34 kcal/min.

Subjects: 87 fit, unacclimatized young men, taken from the population of engine-room personnel in the Royal Navy.

Results: Results lead to development of a regression equation:

$$y = \log(b/(c-a)) + e_i$$

where $y = \log$ time to imminent heat collapse

$c =$ climatic variable which considers dry-bulb temp and wet bulb temp in degrees C

$e =$ error associated with the i th observation

Consequently, this lead to development of safe exposure time as
 $\text{exposure time} = K(p) \exp(y)$

where $K(p)$ is a factor depending on the value of p - the proportion of exposures to be protected, and
 y is the predicted log mean time to imminent collapse.

From the equation and values for percentage of mean time to collapse, tables were constructed and included to show the durations to nearest minute of safe exposure to environments within the range of thermal severity studied for unacclimatized men, working at roughly 310 Joules/sec or 4.34 kcal/min.

As mentioned by the authors, the use of the recommendations provided for exposure time will depend on the population at risk having been adequately represented by the sample of subjects who participated in the series of investigations described here.

Document No: 103

Title: EFFECTS OF SLEEP LOSS AND STRESS UPON RADAR WATCHING

Authors: Bergstrom, Bengt, Gillberg, Mats, and Arnberg, Peter

Agency: Institute of Military Psychology, Stockholm

Date: 1973

Stressors: Sleep deprivation for 78 hours; unpleasant electric shock

Tasks: A 40 minute radar signal detection watch during which time 8 signals were presented. The performance test was taken after 6, 30, 54, 66, and 78 hours without sleep. The shock stressor was administered only on the final day. Shocks were given at regular intervals of not less than 1 minute before the appearance of any target.

Subjects: 30 of the "most reliable" men in a Swedish Army Company.

Results: There were no differences between experimental and control groups during the first six hours when almost 100% of the targets were detected. After 30 hours of sleep loss, the average detection rate was about 90%, and after 54 and 66 hours, the rates were 80% and 70% respectively.

The shock stress on the final day did not affect performance in the control group, and actually improved detection probability in the experimental group significantly, compared to their performance at 54 and 66 hours. However, their overall level of performance was still significantly inferior to that of the control group, who detected all targets.

Document No: 183

Title: EXPERIMENTAL STUDIES OF PSYCHOLOGICAL STRESS IN MAN

Authors: Barkun, Mitchell M., Bialek, Milton M., Kern, Richard P.,
and Yagi, Kan

Agency: U.S. Army Leadership, Human Research Unit, Presidio of
Monterey

Date: 1962

Stressors: Aircraft emergency
"Misdirected" artillery shells
Radioactive fallout
Forest fire
Explosion, involving apparent responsibility of subject for
having caused harm to another

Subjects: Soldiers in their first 8 weeks of Army Basic Training

Results: Subjects exposed to these stress conditions responded in such a way that it met the authors' requirements for research that determines the effectiveness of performance under psychological stress. These criteria included a cognitive response indicating that the threat was accepted as genuine, a significant physiological stress response, and a negative affective response. The simulated aircraft emergency, and the misdirected artillery shells episodes, both of which apparently threatened the subject's life, met all three criteria. The situation in which the subject believed himself responsible for an explosion which seriously injured another soldier, also met all three criteria and produced the most extreme results. Experienced soldiers responded differently from recruits (i.e., they were less affected).

Document No: 116

Title: PERFORMANCE DECREMENT UNDER PSYCHOLOGICAL STRESS

Author: Berkun, Mitchell M.

Agency: Human Resources Research Office, Presidio of Monterey

Date: 1964

Stressors: Threat of crash landing
Threat of artillery fire
Belief of responsibility for injury to another

Task: Repair of malfunctioning telephone to summon aid

Subjects: Army basic trainees

Results: Average performance under threat was significantly poorer than performance of the same task by other subjects who were motivated without threat. Soldiers with more military experience react differently (they do better) in response to the threat condition, and poorer in response to the comparable non-threat conditions.

Document No: 252

Title: HUMAN PSYCHOPHYSIOLOGICAL RESPONSE TO STRESS: SUCCESSFUL
EXPERIMENTAL SIMULATION OF REAL LIFE STRESSES

Authors: Berkun, Mitchell M., Bialek, Hilton M., Yagi, Kan, Berry,
James L., and Kern, Richard P.

Agency: U.S. Army Leadership, Human Research Unit, Presidio of
Monterey

Date: 1959

Stressors: Isolation
"Misplaced" artillery fire
Belief of responsibility for injury to others
A march of 12 miles with little sleep

Task: Repair of malfunctioning radios, telephones, etc., believed to
be necessary to cope with the threatening situation.

Subjects: Various numbers of non-combat experienced Army personnel

Results: This is a preliminary report of a series of studies which
are reported in more detail in Berkun et al., 1962 (also summarized in
this section). This document lacks any details of the results, instead
focusing on conditions that the authors feel are necessary if experi-
mental subjects are to behave in stress studies the way they would in
real life threatening situations.

Document No: 194

Title: SLEEP, PERFORMANCE AND MOOD AFTER THE ENERGY-EXPENDITURE EQUIVALENT OF 40 HOURS OF SLEEP DEPRIVATION

Author: Bonnet, Michael H.

Agency: Naval Health Research Center, San Diego

Date: 1980

Stressors: A march of 20 miles, with a 15 minute break after each hour of march (marching was done with a full pack, on a treadmill, and required approximately 6.5 hours).

Tasks: Vigilance, addition, choice reaction time, tapping, short term memory, symbol substitution.

Subjects: 12 well conditioned Marines who had finished Basic Training.

Results: At the end of the march, performance on addition, vigilance, choice reaction time, tapping, short term memory, symbol substitution, and three mood scales was significantly decremented. The decrements closely approximated those reported in the literature following 40 hours of sleep deprivation. However, recovery rates were very different from those predicted after 40 hours of sleep loss. It was concluded that while changes in performance were probably linked to total energy consumption, the commonly measured sleep variables were not.

Document No: 177

Title: SLEEP LOSS EFFECTS ON MOVEMENT TIME

Author: Buck, Leslie

Agency: Control Systems Laboratory, National Research Council,
Ottawa

Date: 1975

Stressors: One or two nights without sleep

Tasks: A step tracking task that involved different probabilities of directional change of the stimulus to be tracked.

Subjects: 12 males, 18-22 years old participated in one experiment that lasted two days with one intervening night. Eight other male subjects participated in another experiment lasting three days with two intervening nights. The subjects were not otherwise described.

Results: Reaction time for correct responses increased following sleep loss to an extent inversely related to signal probability. Movement times increased following sleep loss to a much greater extent. The author concluded that movement time is a more sensitive index of performance deterioration due to sleep loss and that movement time and reaction time represent separate processes.

Document No: 164

Title: EXPERIMENTAL STUDIES OF PROLONGED WAKEFULNESS

Author: Chiles, Walter D.

Agency: Aeromedical Laboratory, Wright Air Development Center

Date: 1955

Stressors: 56 hours in a link trainer cockpit. Strange alternating pattern in which the subject was allowed to relax and even sleep for the first 18 hours but was required periodically to return to an alerted state; during the next 19 hours he was required to remain alert at all times; during the final 18 hours he was permitted to relax except when requested to alert himself.

Tasks: Reaction time test which included a vigilance component.
Monitoring a moving pointer and designating when it was aligned with a mark at the top of the display.
Flying ILAS passes in the link trainer. However only 2 subjects did this and at the very end of the experiment.

Subjects: Four rated pilots, not otherwise described

Results: The two rated pilots performed satisfactorily in the link trainer. The reaction time and the alertness measures reflected considerable variability in the attentiveness of the subjects.

Document No: 478

**Title: THE IMPACT OF ABNORMAL HOURS OF WORK ON VARIOUS MODES OF
INFORMATION PROCESSING: A PROCESS MODEL ON HUMAN COSTS OF PERFORMANCE**

Authors: DeVries-Griever, A.H.G., and Meijman, Th.F.

**Agency: Institute for Experimental and Occupational Psychology,
University of Groningen, The Netherlands**

Date: 1987

Stressors: "Abnormal and irregular" hours of work

Subjects: N/A a theoretical article

**Results: A process model of human costs of performance at abnormal
hours of work is presented (reproduced on the following page).**

Abnormal hours of work and information processing

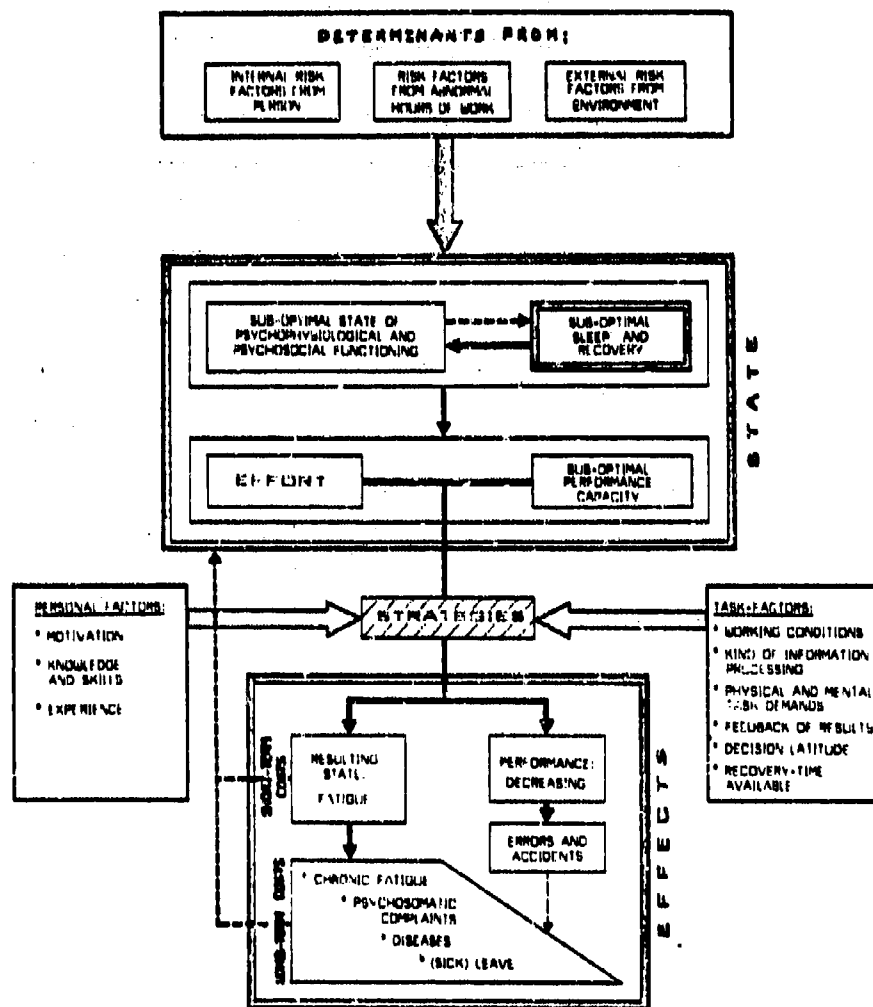


Figure 1. A process model of human costs of performance at abnormal hours of work.

Document No: 304

Title: ASSESSING PERFORMANCE UPON ABRUPT AWAKENING FROM NAPS FROM QUASI-CONTINUOUS OPERATIONS

Authors: Dinges, David F., Orne, Martin T., and Orne, Emily Carota

Agency: The Institute of Pennsylvania Hospital and the University of Pennsylvania, Philadelphia

Date: 1985

Stressors: Up to 54 hours of sleep deprivation.

Subjects: 20 males and 15 females ranging in age from 18 to 30 years (apparently college students)

Results: Performance measures included reaction time in answering a telephone call that disrupted a 2-hour nap following various amounts of sleep deprivation (6, 18, 30, 42, or 54 hours). A sequential subtraction test described as a "challenging" cognitive task was also used. Sleep deprivation increased the amount of deep sleep in the naps and this was associated with greater post-nap cognitive performance decrements. Reaction time performance was related to stage of sleep prior to awakening, and circadian placement of the naps also modulated the post-nap cognitive decrement.

The authors stated that the amount of slow-wave sleep seen in the subjects related most closely to the cognitive decrement upon awakening and suggested that something accumulates psychophysiological during slow-wave sleep that makes it difficult for subjects to function cognitively when they are aroused within close temporal proximity of the slow-wave sleep process. This period of confusion upon awakening has been called sleep inertia.

With respect to circadian effects, the authors state that from the standpoint of napping in quasi-continuous work settings, particularly those that may require optimum performance at a moment's notice, 2 hour naps in the circadian trough should probably be avoided. This is clearly counter intuitive in that sleep tendency is higher near the circadian trough than near the peak. In addition, naps should probably be taken before sleep loss accumulates beyond 36 hours, because more severe cognitive performance decrements can be expected upon awakening from naps taken after this time.

Document No: 462

Title: THE EFFECTS OF COMBAT LOSSES AND FATIGUE ON COMBAT PERFORMANCE

Author: DuPuy, T.N.

Agency: T. N. DuPuy Associates

Date: 1979

Historical data from eight campaigns involving sustained combat for periods of 11 to 56 days were analyzed for the effect of fatigue on unit effectiveness. It is postulated that fatigue is reflected in: (1) casualty rates; (2) score effectiveness rates (casualty inflicting capability with influences of factors such as weather and terrain factored out); and (3) an interrelationship of casualty and score effectiveness rates and measures of combat intensity.

It is shown that these indicators generally declined over time in relation to the length of combat without relief. The evidence of fatigue, as reflected by these indications, was shown to be greater for the attacker than the defender.

The following conclusions are drawn:

1. The effectiveness of military formations, from division through corps to field army, can be measured in terms of Fatigue Indicators, which reflect a combination of performance criteria, of which the most important seem to be the ability to inflict casualties and the intensity of combat (as measured by both casualties incurred and a combat intensity factor).
2. The significance of these fatigue indicators is greater for the attacker than for the defender, since the attacker has the initiative, and the defender is forced to respond to that initiative, regardless of the fatigue status of defending units.
3. For larger formations, such as corps or armies, in extended campaign operations, the decline in performance can be represented by a gradually increasing fatigue factor with a decline of about 1.65% per day at the outset of the campaign, up to a maximum decline of about 2.70% per day by the 25th day.
4. For the divisions participating in such campaigns, the daily decline in performance is about 6.79% per day during brief periods of intensive combat; it is about 1.94% per day for longer periods in which the divisions are actively engaged less than 80% of the time; it is about 1.39% for periods in which the divisions are engaged 50% or less of the time.
5. During lulls, or periods in which divisions are not committed to active combat, they recover previously lost combat effectiveness (as manifested in fatigue indicators) at a rate of about 5.94% per day.

6. Further research is required to verify these preliminary conclusions, and to determine the effect of replacements upon average figures for decline and recovery of combat performance capability.

Document No: 295

Title: EFFECTS OF THE LOSS OF 100 HOURS OF SLEEP

Author: Edwards, A. S.

Agency: University of Georgia

Date: 1941

Stressors: Up to 100 hours without sleep

Tasks: Reaction time, tapping, aiming, hand steadiness, color perception, visual acuity, depth perception, learning, memory, and performance on the ACE psychological examination.

Subjects: 13 men and 4 women, not otherwise described.

Results: Severe deterioration in the performance of most tasks after 72 hours. Subjects had to be awakened repeatedly during the tests.

Lapses or pauses in observing rate and brief bursts of observing were viewed as early indicators of sleep deprivation-induced performance decrement. These are believed to increase in frequency and duration as sleep deficit increases.

Document No: 172

Title: PERFORMANCE CHANGES DURING SUSTAINED OPERATION OF A COMPLEX PSYCHOMOTOR TASK

Authors: Ellingstad, V. S., and Heimstra, N. W.

Agency: Dept. of Psychology, University of South Dakota

Date: 1970

Stressors: Continuous work at a variety of tasks for 15 hours.

Tasks: Tracking (similar to automobile steering)
Vigilance
Reaction time
Mental multiplication
Digit span

Tracking performance was the primary task. Subsidiary performance tasks included the vigilance task, reaction time, mental multiplication and digit span.

Subjects: 15 male graduate and medical students.

Results: Significant decrements in tracking performance, as measured both in the amount of time off the target track, and the number of times off target, occurred over the 15 hour session. There was no clearly established performance decrement on the subsidiary tasks; rather there was marked variability in performance over the course of the experimental session in the performance of these tasks. Performance on the vigilance task and one of the reaction time tasks actually improved (probably a learning effect).

Document No: 527

Title: EFFECT OF HEAT AND CHEMICAL PROTECTIVE CLOTHING ON COGNITIVE PERFORMANCE

Authors: Fine, B., and Kobrick, J.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1987

Stress: Sedentary soldiers clad in NBC gear in extreme climates.

Tasks: Certain aspects of those performed by individual members of FDC teams, by forward observers, and by Army communication personnel.

Tasks rely on cognitive skills relevant to:

- site computation;
- codebook processing for messages and map coordinates; and
- map plotting.

Subjects: 23 male soldier volunteers, screened for medical fitness and able to read without glasses. Subjects were trained in the tasks and use of the MOPP-IV gear.

Results: After 4-5 h of exposure in a climatic chamber to a moderately hot environment, the cognitive performance of a group of highly trained soldiers clad in the MOPP-IV configuration of NBC protective clothing began to deteriorate markedly. By the end of 7 h of exposure to heat, increases in percent group error ranged from 17 - 23% over control conditions on investigator paced tasks. Virtually all of this decrement was due to increases in errors of omission. The productivity of the group on a self-paced task (map-plotting) decreased by approximately 40% from control conditions after 6h in the heat, but accuracy of plotting did not appear to be markedly affected.

While not dealing with physical activity or physically stressful tasks, the study is of interest because of the relevance of the subjects tasks to real world army tasks. The duration of the study, 8 hrs, is also significant.

Document No: 160

Title: SUSTAINED OPERATIONS AND SLEEP DEPRIVATION: EFFECTS ON INDICES OF STRESS

Authors: Francesconi, R. P., Stokes, J. W., Banderet, L. E., and Kowal, D. M.

Agency: U.S. Army Research Institute of Environmental Medicine, Natick

Date: 1978

Stressors: One team was sleep deprived for 48 hours while the second team was deprived of sleep for two consecutive 39-hour periods, separated by a 33 hour rest interval

Tasks: Several tasks related to artillery fire direction team performance including responding to radio messages containing coded information, plotting grid coordinates, slide rule computations, maintaining written records, and transmitting data and instructions to a control center which simulated the artillery battery.

Subjects: Two trained artillery fire direction teams, each consisting of five men

Results: Performance was evaluated for accuracy and timeliness. It is stated that several measures of team performance showed fatigue related decrements but no performance data are presented. Rather, the reported data are limited to changes in various physiological indices of stress response. It is stated that one team exercised its right to withdraw from the study after 48 hours of sustained operations.

Document No: 143

Title: EFFECTS OF 71 HOUR PARTIAL SLEEP DEPRIVATION ON HUMAN
BEHAVIORAL AND PHYSIOLOGICAL RESPONSE MEASURES

Authors: Frazier, Thomas W., Benignus, Vernon A., Every, Martin G.,
and Parker Jr., James F.

Agency: Biotechnology, Inc.

Date: 1971

Stressors: Sleep limited to 3 hours in every 24, up to a period of
72 hours total.

Subjects: 14 males, aged 18-25, not otherwise described.

Tasks: Vigilance, involving a simple signal detection task.

Results: There were three displays to be monitored with different
signal rates. Daily performance means showed a progressive performance
decrement over 3 days of limited sleep. Both signal detection measures
and response latency showed progressive loss of performance capability.
A measure of observing rate of the several displays also showed a reduc-
tion in response effort; significance was obtained only in the case of a
variable-interval schedule.

Lapses or pauses in observing rate and brief bursts of observing
were viewed as early indicators of sleep deprivation-induced performance
decrement. These are believed to increase in frequency and duration as
sleep deficit increases.

Document No: 403

Title: PRELIMINARY RESULTS OF A PSYCHOLOGIST'S OBSERVATION AND PARTICIPATION WITH A COMBAT UNIT DURING CONTINUOUS OPERATIONS

Authors: Futterer, James W.

Agency: Community Mental Health Activity, William Beaumont Army Medical Center, El Paso, Texas

Date: 1982

Stressors: Continuous operations over a 2-week period during REFORGER 82.

Tasks: All operations associated with an armored cavalry unit. Direct observation and personal conversations with the troops; no performance measurement.

Subjects: Various. Personnel in the Battalion Aid Station, in the Tactical Operations Center, and line troop commanders.

Results: Authors reported that he personally got only 2.8 hrs sleep per 24 during first exercise week and 2.1 hrs per 24 during second week, even though he had no assigned duties. He observed the troop commander to average less than 1 hr of sleep per 24.

The effects of sleep deprivation and other operational stress factors were "progressive and dramatic". Among the effects observed:

- (1) Inability (after 2 or 3 days of continuous operations) of a troop commander to take effective action against being encircled although he was warned of the danger by a neighboring unit.
- (2) Increased time for leaders to accomplish routine tasks (deployment and positioning of platoons).
- (3) Increased errors in map reading and locating themselves on the ground in relation to maps.
- (4) Increased errors in radio transmissions; longer transmission times; increased use of incorrect call signs; irritability.
- (5) Decreased information flow between combat elements and up the chain, resulting in unnecessarily short notices to supporting elements and disruption of their functioning.
- (6) Increased vehicle accidents involving serious injury or property damage (after 3-4 days of exercise play).
- (7) Lack of cohesion and esprit; reduced "will to continue".
- (8) Increased rumors and misinformation as formal channels of communications became less effective.

Document No: 513

Title: EFFECTS OF LIFTING FREQUENCY AND TECHNIQUE ON PHYSICAL FATIGUE WITH SPECIAL REFERENCE TO PSYCHOPHYSICAL METHODOLOGY AND METABOLIC RATE

Authors: Garg, A., and Saxena, U.

Agency: University of Wisconsin-Milwaukee, Industrial and Systems Engineering

Date: 1979

Stressors: Repeated lifting over 40 min. trial duration: range of frequency of lift (3, 6, 9, and 12 lifts/min); different lifting techniques

Task: Lifting a tote box from the floor to a 0.5 m vertical height.

Subjects: 6 male college students.

Results: Maximum acceptable work was significantly affected by the lifting technique and frequency. The maximum acceptable work load increased with increasing frequency. The minimum metabolic cost occurs at 9 lifts per minute or 70cal/kg-m. The free style technique produced the largest maximum acceptable work loads. In addition, lifting technique and frequency had a significant effect on metabolic rate. At lowest work pace, muscle strength is the limiting factor in selecting maximum weight of lift. Physiological fatigue criteria results in more liberal standards at low lift frequency.

Document No: 528

Title: PREDICTING HEART RATE RESPONSE TO WORK, ENVIRONMENT, AND CLOTHING

Authors: Givoni, B., and Goldman, R.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1973

Task: N/A. Report presents a prediction equation derived from previous studies.

Subjects: 8 heat acclimatized subjects on a treadmill task.

Results: A prediction equation for heart rate response to work, environment, and clothing is developed. The equation predicts a dynamic response patterns of heart rate with time of exposure for both a constant activity and environment, and with varying activity, environment, and clothing during an exposure. Activity is represented as total metabolic energy production, in watts; clothing is represented as the thermal insulation of clothing, in clo units; environment is represented through air temperature is in degrees C and ($E_{req}-E_{max}$), the metabolic and environmental heat load not dissipated through evaporative cooling of clothing and environment.

Document No: 197

Title: EFFECTS OF SLEEP DEPRIVATION ON SHORT DURATION PERFORMANCE MEASURES COMPARED TO THE WILKINSON AUDITORY VIGILANCE TASK

Authors: Glenville, Marilyn, Broughton, Roger, Wing, Alan M., and Wilkinson, Robert T.

Agency: Psychophysiology Section, Medical Research Council, Applied Psychology Unit, Cambridge

Date: 1978

Stressors: One night's sleep deprivation

Tasks: Simple reaction time; choice reaction time, short term memory, handwriting (time limited), and auditory vigilance.

Subjects: Eight volunteer males aged 20-46, not otherwise described

Results: Performance on the two reaction timed tests was significantly impaired by the one nights loss of sleep, but not as much as performance on the vigilance task. The short term memory test failed to show any adverse effects of sleep loss and the same was true of the handwriting test. The performance tests (other than the Wilkinson vigilance test) were all of very short duration (10 minutes). The authors conclude that the two short reaction time tests, which were given on portable equipment, should be sensitive to detecting the effects of sleep loss and assessing the levels of alertness in the field.

Document No: 530

Title: PHYSIOLOGICAL RESPONSES DURING WORK IN HOT HUMID ENVIRONMENTS

Authors: Gupta, J., Swamy, Y., Dimri, G., and Pichan, G.

Agency: Defence Institute of Physiology and Allied Sciences, New Delhi

Date: 1981

Stressors: Submaximal fixed work rates (400, 500, and 600 kgM/min) in a climatic chamber at comfortable, hot humid, and very hot humid climatic conditions. Various levels of exercise were administered over a 90 minute duration, or until the subject could not maintain the assigned level of work, heart rate reached 180 beats per minute or above, or rectal temperature reached 40 degrees C, whichever came first.

Tasks: Submaximal work performed on a bicycle ergometer.

Subjects: 6 young, healthy Indian soldiers, well acclimatized to the heat.

Results: A significantly higher VO_2 cost occurs during 400kgM/min of work in hot and very hot humid environments whereas, in the higher rates of work, the changes were not significant. The cardiac frequency showed a significantly higher rise during different grades of activities in hot and very hot environments except in the highest work rate in hotter environments, possibly due to attainment of maximum heart rate. The duration of continuous physical efforts in various grades of activities decreased significantly in hot humid environments over those in the comfortable temperature.

In hot humid environments, work performance decreased due to early attainment of maximum heart rate, reduction in VO_2 max, disproportionate rise in rectal temperature, narrowing of the difference between the core and the skin temperature and attainment of maximum sweating rate.

Document No: 005

Title: A STUDY OF RECOVERY FUNCTIONS IN MAN

Authors: Harris, William and O'Hanlon, James F.

Agency: Human Engineering Laboratory, Aberdeen Research and Development Center

Date: 1972

Stressors: Continuous and sustained operations

Tasks: Military tasks in general; this is a review article

Subjects: Military personnel

Results: Concepts of sustained and continuous military operations were examined with respect to the relevant literature. The objectives were to predict behavioral and biological impairments which might result in those operations; and to determine whether the period necessary for recovery following a sustained operation can be ascertained from the literature. It was concluded that those objectives could not be met due to inadequate information. Nonetheless, the literature did provide data which suggest that certain severe impairments may be experienced by soldiers engaging in sustained and continuous operations. It also provided guidelines for the design of studies to collect the required information.

Document No: 426

Title: THE MILITARY PERFORMANCE OF SOLDIERS IN SUSTAINED OPERATIONS*

Author: Haslam, D.R.

Agency: Army Personnel Research Establishment, Farnborough,
Hampshire, England

Date: 1984

Stressors: Limited (1.5 or 3 hrs) or no sleep during 9-day tactical
defensive exercises. Heavy rain.

Tasks: Vigilance rifle-shooting, weapon handling, digging, marching,
patrolling, map-plotting; encoding/decoding grid references; short-term
memory test; logical reasoning test.

Subjects: 3 infantry platoons

Results: All of the no-sleep platoon withdrew from the exercise
after 4 nights without sleep. Moreover, military observers judged them
to be ineffective after 3 nights without sleep.

Vigilance rifle-shooting and the more difficult cognitive tasks
deteriorated most, while simple well-learned tasks like weapons handling
suffered little. There was a direct relationship between the rate of
deterioration and the amount of sleep deprivation, dropping to about 50%
of control condition performance after 9 days for the 3 hr sleep platoon;
to about 35% for the 1.5 hr sleep platoon. The 0-hour sleep platoon fell
to about 66% of control condition performance in just 4 days before they
withdrew. Response to orders as assessed by military observers showed
similar progressive declines, directly correlated with the amount of
sleep deprivation.

In sharp contrast, self-paced tasks (grouping of 5 rounds) showed
essentially no degradation over the full 9 days.

In the later stages of the sleep deprivation period, personal hy-
giene and self care deteriorated. The incidence of falling asleep in-
creased, a few non-commissioned officers ceased to act as leaders but
concentrated on personal survival. Planning for patrols also deterio-
rated markedly.

*For more details of similar studies, see Haslam's work as reported in
Appendix A.

In a second experiment in which 10 infantry soldiers were sleep-deprived for 90 hours, following which they were allowed varying amounts of sleep for several days, the following was noted:

- Vigilance/rifle-shooting began to deteriorate after 1 night without sleep.
- After 3 nights without sleep it fell to 50% of control values. After 4 hrs of uninterrupted sleep, performance "considerably improved".
- Visual illusions were common in this group of soldiers, and were frequent during a visual vigilance test where they accounted for 10% of the false alarms.
- These personnel were judged (unanimously) by military observers to be ineffective in a defensive role after 48 hrs without sleep.

Haslam's conclusions:

1. Soldiers are likely to be militarily ineffective after 48-72 hours without sleep
2. The effects of sleep loss are mainly psychological: mental ability and mood deteriorate, but physical fitness does not
3. Tasks requiring cognitive ability, especially sustained attention, are likely to be impaired after moderate sleep loss
4. Simple, well learned and physical tasks are unlikely to be impaired, even after quite severe sleep loss
5. A small amount of recovery sleep relative to amount lost has very beneficial effects (p. 221).

Document No: 304

Title: SLEEP DEPRIVATION AND NAPS

Author: Haslam, Diana R.

Agency: Army Personnel Research Establishment (U.K.)

Date: 1985

Stressors: 90 hours of wakefulness. Various groups of subjects were allowed either 2 hours of sleep following 90 hours of wakefulness, 4 hours of uninterrupted sleep, or 4 1-hour naps in each 24 hour period.

Tasks: Encoding/decoding tests using military ciphers
 Encoding/decoding grid references
 Decoding messages

Subjects: 10 infantrymen in the 2-hour napping experiment; 6 infantrymen in the 4-hour napping experiment.

Results: After 3 nights without sleep, the subjects' average cognitive performance was 55% of control values. During a test session immediately before the 2-hour nap, when subjects were advised that they were to have a 2-hour nap, performance improved by 30%, to 85% of control values, indicating the considerable effect that just anticipation of an imminent nap can have even on severely sleep deprived subjects.

In the second experiment, there were no significant differences in cognitive performance between subjects who received four hours of interrupted sleep every 24 hours, vs. those that received 4 1-hour naps in each 24 hour period. The author concludes that this illustrates the utility of four hours of sleep whether it is received in an uninterrupted block or not.

It should be noted that the encoding and decoding tests used in this experiment were very short (10 minutes each). The results might have been quite different if longer performance periods had been used.

Document No: 179

Title: THE FUTURE BATTLEFIELD: HUMAN DIMENSIONS AND IMPLICATIONS
FOR DOCTRINE AND RESEARCH

Author: Hegge, Frederick W.

Agency: Walter Reed Army Institute of Research

Date: 1982

Stressors: Sustained warfare; unprecedented lethality of weapons

Subjects: N/A - not an experimental study. Directed at all military personnel under future battlefield conditions

Conclusions (in brief):

- Leadership and command functions will be particularly susceptible to the stresses and strains inherent to the sustained battlefield
- Intense fatigue will be a critical factor affecting performance sustainability at all levels within the military organization
- Force attrition is expected to be very high and replacements very scarce
- Casualty management will require new methods of medical intervention and procedures for evacuation
- Female personnel will constitute a significant proportion of the troops fielded in response to a main force attack on NATO
- Pharmacological supports of military performance appear promising, particularly in regard to reduction of fatigue, anxiety and fear.

Document No: 458

Title: THE EFFECT OF TASK DURATION AND WORK-SESSION LOCATION ON PERFORMANCE DEGRADATION INDUCED BY SLEEP LOSS AND SUSTAINED COGNITIVE WORK

Authors: Haslegrave, Ronald J. and Angus, Rogart G.

Agency: Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, Canada

Date: 1985

Stressors: 54 hours of sleep deprivation

Subjects: 12 female students from University of Toronto, aged 19-24.

Tasks: Serial reaction time, simple iterative subtraction, encoding/decoding, complex iterative subtraction, and logical reasoning.

Results: In general, task performance was relatively stable during the 1st day (0900 - 2100) and even improved somewhat over time. However, performance degraded abruptly in the early hours of the second day (0300) and never reached the 1st day's level again. A similar abrupt drop in performance was seen in the early morning (0300) and subsequent hours of the third day. The following are estimates derived from the data plots of the amount of degradation that occurred, on average:

	<u>2nd day</u> <u>vs. 1st</u>	<u>3rd day</u> <u>vs. 2nd</u>	<u>3rd day</u> <u>vs. 1st</u>
Serial reaction time	76%	66%	51%
Logical reasoning	69%	56%	38%
Simple subtraction	69%	56%	38%
Complex subtraction	68%	60%	32%

Measures are in terms of correct responses per minute.

Document No: 201

Title: CHANGES IN ATTENTION ALLOCATION IN A MULTI-COMPONENT TASK
UNDER LOSS OF SLEEP

Author: Hockey, G. R. J.

Agency: Medical Research Council, Applied Psychology Unit,
Cambridge

Date: 1970

Stressors: One night without sleep

Tasks: Pursuit tracking (primary) and vigilance for peripherally
presented visual signals (secondary)

Subjects: 12 volunteer Naval ratings

Results: It was hypothesized that environmental treatments thought to change arousal in opposite directions (noise and loss of sleep) will also produce opposing changes in the degree of selectivity in attention allocation. Subjects performed a primary tracking task while simultaneously monitoring an array of light sources for occasional signals. The performance tests were conducted in a background of 70 dB broadband noise. The effect of sleep loss was to significantly impair performance of the primary task, and to reduce the advantage of high probability sources over low probability sources within the subsidiary task (i.e., a loss of selectivity). The author concludes that the results compliment those found in previous experiments with noise in which changes in attention allocation move in the opposite direction (an increase in selectivity) and thus supports the view that selectivity is a function of arousal level.

Document No: 109

Title: THE OPERATIONAL CONSEQUENCES OF SLEEP DEPRIVATION AND SLEEP DEFICIT

Authors: Johnson, L. C. and Naitoh, P.

Agency: AGARD (Advisory Group for Aerospace Research and Development) NATO

Date: 1974

Stressors: 36-48 hours of total or partial sleep loss

Tasks: Not specific. All of the tasks performed primarily by aircrew members, although the results may be regarded as more general in application.

Subjects: Not applicable. This is a review article.

Results: "Effects of total sleep loss, partial sleep loss, and sleep stage deprivation are reviewed with particular attention to performance decrement and operational consequences. Within the 36-48 hour range of total sleep loss most likely to be experienced by aircrew personnel, no consistent or uniform performance decrement has been found in operational studies even though laboratory studies have found decrement on certain types of tasks. Of major importance are the type of task, the setting in which the task is to be performed, and the individual. Physiological changes are minimal during moderate sleep loss, but mood changes are clearly noticeable. The most likely sleep problems for aircrew members are those associated with disruption of sleep-wakefulness cycles and partial sleep loss. Consistent performance decrement is difficult to find, but marked increase in fatigue is a common problem. Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses. Deprivation of sleep stage REM or sleep stage 4 produces no behavioral changes supportive of earlier beliefs that these two stages, especially stage REM, were necessary for effective waking behavior." (p. 1)

"What are the operational consequences of sleep loss and sleep deficit? Short of prolonged sleep loss of greater than 60-72 hours, it is difficult to categorically state what the effects of sleep loss on performance will be. Whether a performance decrement will occur during sleep loss depends upon a complex interaction of task, situational and personal factors. The nature of the task and its meaning to the subject, particularly its survival value, are of primary importance in the type of sleep-deprivation effects which occur. In the majority of instances, performance decrement occurs when the subject becomes sleepy. If the subject can be motivated to remain alert, performance decrement is difficult to detect. The conclusion by the Tufts group at the end of their 1949 review is still appropriate to state at the end of this review. "Subjective attitude (mood, appearance, and behavior) is the primary factor seriously affected by sleep loss." There have been no studies that have

conclusively demonstrated consistent performance decrements as a result of partial sleep loss, even though numerous illustrations of sleep disruption and sleep deficits have been presented." (p. 33).

"There is still a paucity of data on individual susceptibility to sleep loss effects and techniques to measure individual differences..." (p. 34)

"At this time the amount of sleep spent in each sleep stage does not appear to have important operational consequences. The amount of sleep, and whether the sleep is broken into several segments over the 2 hour period are more important." (p. 35).

"Perhaps the most important question is the one for which there are little data: i.e., following missions that result in sleep deficits and the cumulative build up of fatigue, what is the necessary recovery period?" The little data available suggest that the recovery period is related to the duration of the mission. Within the 36-48 hour range of total sleep loss most likely to be experienced by aircrew personnel, no consistent or uniform performance decrement has been found in operational studies even though laboratory studies have found decrement on certain types of tasks.

"Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses." (p. 1).

Document No: 416

Title: SLEEP DEPRIVATION AND PERFORMANCE

Author: Johnson, Laverne C.

Agency: Naval Health Research Center, San Diego, CA

Date: 1980

Stressor: Sleep deprivation

A summary article concerning what was known about the effects of sleep loss on performance as of 1980. Topics include the "lapse hypothesis" and alternatives to it; variables that modify the effects of sleep loss (fatigue; task variables, psychological factors, situational factors, behavioral periodicity); the effects of reduced sleep and fragmented sleep; and the effects of recovery sleep.

Document No: 487

Title: PHYSIOLOGICAL AND BEHAVIORAL RESPONSES TO THE STRESS OF SLEEP LOSS

Author: Johnson, Laverne C.

Agency: Naval Health Research Center, San Diego, CA

Date: Uncertain. This is an excerpt from a larger document that was not identified.

Stressor: Sleep loss in various amounts to 60 hours or more

Tasks: N/A. This is a summary paper

Results: Author's abstract:

Total sleep loss of greater than 60 hours may be expected to produce some physiological, biochemical, performance, behavioral, and mood changes. The degree of change depends upon the individual but, as sleep loss progresses beyond 60 hours, changes will eventually be evident in all areas; however, the behavioral significance of the changes will vary. Total sleep loss of 40-48 hours would probably be the upper limit with loss of 30-36 hours more likely. These amounts of sleep loss can be tolerated without debilitating changes in the physiological system. In most instances, if any effects are noted, they will first be evident by changes in mood. Performance changes will be minimal if the tasks are brief, self-paced, highly motivating, and feedback is given as to adequacy of response. Tasks that require sustained vigilance and attention, use of newly acquired skills, retention of new information, and which necessitate long periods to complete are more likely to show sleep-loss effects. Most of the decrement will occur during periods of brief sleep. These effects are more likely to occur during the early morning hours when body temperature is low. Performance workload should be reduced during hours when sleep would normally occur, regardless of actual time of day.

Document No: 532

Title: THE PHYSIOLOGICAL COST OF CARRYING LOADS IN TEMPERATE AND HOT ENVIRONMENTS

Authors: Kamon, E., and Belding, H.

Agency: University of Pittsburgh, Department of Occupational Health

Date: 1971

Stressors: Considered three weights (10, 15, 20 kg) in three thermal conditions: neutral, dry, (20 degrees C, 68 degrees F), warm dry (35 degrees C, 95 degrees F), or hot dry (45 degrees C, 113 degrees F). Each experiment presented one of four combinations of speed and grade (4 or 5 km/hr; 0 or 4% grade). Walking speed were based on preliminary trials of subjects, such that the resulting metabolic cost was minimized. The experimental test lasted 65 minutes, composed of 5 minutes of rest, 10 minute warm-up, 5 minute rest, and a series of 5 minute periods of walking, carrying, sitting, carrying, walking, sitting, walking, carrying, sitting.

Tasks: Manual material handling in hot environment.

Subjects: Three pretrained, preacclimatized subjects, 20-24 years old.

Results: Ambient temperature did not affect metabolic cost. The optimum walking speed in terms of energy expenditure per unit of distance was found to be about 4 to 5 km/hr. This speed was similar for all three subjects, even though one had shorter legs, a higher step frequency, and a 7% higher energy cost per kilogram of body weight.

For these experiments, where the load was carried by the arms against the abdomen, with the hands gripping the far corners of the carton, the metabolic cost per unit of weight of load was 1.3 to 2.3 times greater than for carrying an equivalent amount of body weight. The loss in efficiency from carrying loads in front of the body may be attributed mainly to the increase in step rate.

During uphill walking, the step rate was lower. As a result, the loss in energy efficiency was less than on ground, both per unit of total weight and per unit of weight of load. Despite this, the actual energy cost for carrying loads uphill was greater.

A regression of heart rate on metabolic rate showed that heart rate increases with ambient temperature over that at 20 degrees C for any given metabolism. Heart rate increased with increased loads. Subjects found it hard to accomplish the required 5 minute period of carrying 20 kg even at 20 degrees C, which supports the theory that if a steady state is not reached the load is a fatiguing one. In terms of cardiac cost, it seems that for repetitive handling of bulky loads in front of the body, 15 kg is about the upper limit.

Document No: 520

Title: PHYSIOLOGICAL LIMITS IN LIFTING

Authors: Khalil, T., Genaidy, A., Asfour, S., Vinciguerra, T.

Agency: University of Miami, Department of Industrial and Biomedical Engineering

Date: 1985

Tasks: Repetitive lifting versus bicycling task

Results: Workload is equal to the frequency x load x height of lift. This combination determines the value of VO_2 max attainable. VO_2 max values for a lifting task were significantly lower than those obtained for a bicycling task. With low lifting frequencies, the individual's muscular strength became the limiting factor in achieving a workload comparable to a highly dynamic task such as bicycling.

If limits of continuous work are based on physiological limiting criteria, they should be based on the VO_2 max attainable for the particular lifting task under investigation. Physiological capacity is a valid factor for determining lifting capacity only in the frequency range of 3 to 9 lifts per minute.

In lifting, the task demands which are determined by the factors of load, frequency, and height of lift must be met with adequate human capacities to meet the demands. Strength, physiological capacity, and psychological acceptance of the performed activity are generally recognized as important determinants of lifting capacity. All three are needed for optimal determination of lifting capacity.

Document No: 585

Title: EXERCISE IN A COLD ENVIRONMENT AFTER SLEEP DEPRIVATION

Author: Kolka, M., Martin, B., and Elizondo, R.

Agency: Indiana University School of Medicine for the US Army
Research Institute of Environmental Medicine

Date: 1984

Stressors: Subjects exercised to thermal comfort in a cold environment (0 degrees C) after normal sleep and following a 50 hour period of sleep deprivation. Sleep deprived and normal sleep experiments were separated by at least 4 days, and all were conducted between 0800 and 1200 hr.

Ambient temperature was 0 degrees C during the tests.

Tasks: Subjects performed two treadmill walks for 45 minutes at 1.65 m/sec at a voluntarily chosen grade. The grade was adjusted to provide a balance between thermal comfort and exercise fatigue, to try to continue the exercise as long as possible.

Subjects: Six men and 1 woman in excellent health.

Results: Resting core temperature taken before the subject entered the cold environment was significantly lower following the 50 hour period of wakefulness. Rectal temperature was not different after 15 minutes of exercise during the two exposures, suggesting that the subjects stored heat more rapidly during the first 15 minutes of exercise after sleep deprivation.

No significant differences in self-chosen exercise intensity, heart rate, metabolic rate, or exercise time were evident between the control and sleep deprived exposures. Fifty hours of sleep deprivation failed to alter the core temperature response during exercise in severe cold stress, and subjects chose identical work rates to minimize fatigue and cold sensation. The cold stress appeared to provide the motivation for the work and this was identical under the two conditions.

The results suggest that the 50 hour sleep deprivation period was not a true physiological stress during exercise in a cold environment.

Document No: 156

Title: SOLDIER PERFORMANCE IN CONTINUOUS OPERATIONS: ADMINISTRATIVE MANUAL FOR A BRIEFING AND SEMINAR FOR COMMAND AND STAFF PERSONNEL

Authors: Kopstein, Felix, Siegel, Arthur, Conn, Joseph, Caviness, James, Sliffer, William, Ozkaptan, Halim, and Dyer, Fred

Agency: U.S. Army Research Institute, Field Unit, Ft. Benning

Date: 1985

Stressors: Continuous operations
Sleep loss

Tasks: A large number of "critical" tasks associated with mechanized infantry, armor, FIST, and artillery operations

Subjects: Not applicable. The manual is designed to apply to all classes of soldiers assigned to the four types of combat units described above.

Results: Degradation factors for the various critical tasks performed by each of the above occupational specialties, as a function of 1-5 days of continuous operations, are presented without supporting evidence. (Documents nos. 110 and 181 should be consulted for details). It is stated that the following are effects of prolonged continuous operations on soldiers performance: decreased vigilance, reduced attention, slowed perception, inability to concentrate, faulty memory, slowed comprehension, slowed responding, increased omissions of tasks, encoding/decoding difficulties (transformation of data or processing of information), fuzzy reasoning, communication difficulties, and mood changes (irritability, depression, apathy).

Document No: 210

Title: HUMAN PERFORMANCE IN CONTINUOUS OPERATIONS: VOLUME II.
MANAGEMENT GUIDE

Authors: Kopatein, Felix F., Siegel, Arthur I., Wilson, Lawrence B.,
and Ozkaptan, Halim

Agency: U.S. Army Research Institute for the Behavioral and Social
Sciences

Date: 1979

Stressors: Continuous operations
Fatigue due to loss of sleep
Diurnal rhythms
Low light levels, darkness
Stress (not defined, but "produced by a variety of
factors in the environment")

Tasks: A multitude of "critical" tasks associated with mechanized
infantry, armor, FIST, and artillery operations

Subjects: Not applicable. The recommendations are intended for
managers of personnel involved in all phases of ground combat operations.

Results: Not strictly applicable. Chapters are presented on how
abilities and performance decline as a function of loss of sleep, diurnal
rhythms, night operations, and "stress"; strategies are presented for
human resources management, including performance in continuous opera-
tions; management techniques are suggested for diagnosing and reducing
deficiencies; and methods of assessing human resources, including how to
gauge the individual, teams and units, and conserve and maximize human
resources, are presented.

Document No: 304

Title: AVIATOR PERFORMANCE IN WEEK LONG EXTENDED FLIGHT OPERATIONS
IN A HELICOPTER SIMULATOR

Authors: Krueger, Gerald P., Armstrong, Richard N., and Cisco,
Ronald R.

Agency: U.S. Army Aeromedical Research Laboratory, Ft. Rucker,
Alabama

Date: 1985

Stressors: 66 hour, five-day flight schedule with 4 hours sleep per
night. 14 hour missions for 4 successive days; 10 hour mission on the
5th day.

Subjects: 6 qualified pilots

Results: A large number of flight parameters reflecting pilot per-
formance were recorded. In addition, during each flight the co-pilot
participated in simulated navigational tasks to assess auditory attention
and short term memory. Pilots maintained simulator flight parameters to
within acceptable tolerances of assigned headings, air speeds, and alti-
tudes, even during the morning of the fourth day of schedule. However,
various cognitive and judgemental errors were made, and flight surgeons
deemed them unsafe to fly by the third night. Nevertheless, it is stated
that pilots continued to fly well to the fifth day.

Document No: 566

Title: COMPARISON OF FIVE MODES OF CARRYING A LOAD CLOSE TO THE TRUNK

Authors: Legg, S. L., and Mahanty, A.

Agency: Army Personnel Research Establishment, Farnborough

Date: 1985

Stressors: Weight fixed at 35% of subject body weight.
Five different modes of carrying were investigated: military backpack with tubular frame, backpack without frame, backpack and pouches on waist belt; backpack and front pack, and trunk jacket.

Tasks: Carry load over fixed distance using various modes.

Subjects: 5 fit young males.

Results: Cardiorespiratory and metabolic costs of the five modes of carry were not significantly different. However, the backpack/front pack, and trunk jackets were rated as significantly more comfortable than backpack with frame and backpack without frame.

The backpack/front back mode caused the greatest reduction in MVV, likely due to the weight of the front pack on the chest. While this restriction was not perceived as causing any great discomfort while carrying the loads at moderate work rates (approximately 30% VO_2 max), the importance lies more in the potential effect on the performance of demanding tasks which require high ventilatory rates, immediately following load carriage.

The optimum method will depend on the nature of the task, the environmental condition, personal and other factors.

Document No: 533

Title: PHYSIOLOGICAL EFFECTS OF CONTINUOUS OR INTERMITTENT WORK IN THE HEAT

Author: Lind, A.

Agency: US Army Quartermaster Research and Engineering Center, Natick, MA

Date: 1963

Stressors: During 8 hr exposures to three climates with dry and wet bulb temperatures of 29.4 and 23.9, 36.7 and 23.6, and 41.1 and 28.3 degrees C, respectively, subjects expended approximately 2100 kcal in both nearly continuous level of activity and intermittent bouts of much harder work interspaced by longer periods of rest.

Tasks: Treadmill walking, intermixed with light or sedentary activity over a period of 8 hours.

Subjects: Two young fit soldiers, unacclimatized.

Results: Due to the small subject sample, the results should be considered indicative rather than definitive of physiological response.

Extension of exposures to periods of up to 8 hr per se did not demonstrably change the levels of rectal temperature, pulse rate, or weight loss found by the 2nd hour of exposure in the climates examined. In prescriptive climates, in which the level of thermoregulation depends on the rate of work rather than on the environment, when the energy expenditure was 2100 kcal in 8 hr, either continuously at a moderate rate, or intermittently at a high rate with compensatory rest pauses, the physiological cost was similar, as judged by rectal temperature, pulse rate, and weight loss.

Results support the view that physiological responses to work in the heat have often been shown to be higher in the afternoon than in the morning.

Document No: 130

Title: EFFECTS OF EXERCISE, BEDREST, AND NAPPING ON PERFORMANCE
DECREMENT DURING 40 HOURS

Authors: Lubin, A., Hord, D., Tracy, M.L., and Johnson, L. C.

Agency: Naval Health Research Center, San Diego

Date: 1975

Stressor: 40 hours without sleep

Tasks: Auditory vigilance, addition, word memory

Subjects: Young, male volunteers from the Naval Hospital Corps
School

Results: The subjects were maintained on a 60-minute treatment 160 minute testing schedule for 40 consecutive hours. During the treatment phase, 10 subjects bicycled, 20 subjects controlled EEG activity during bedrest, and 10 subjects napped. The bedrest group showed significant impairment on all eight measures, and thus gave no support to the forced rest theory of the sleep function. The exercise group was worse than the nap and bedrest group for all measures. In spite of fragmented, reduced sleep (about 3.7 hours per 24), the nap group had no impairment on 6 of the measures. The authors suggest that exercise increases the impairment due to sleep loss, and naps reduce or remove this impairment. Bedrest is not a substitute for sleep.

Document No: 587

Title: EFFECT OF SLEEP DEPRIVATION ON TOLERANCE OF PROLONGED EXERCISE

Author: Martin, B.

Agency: Indiana University, Medical Sciences Program

Date: 1981

Stressors: Acute loss of sleep (36 hrs without sleep)

Tasks: Treadmill walking

Subjects: 8 subjects

Results: During prolonged treadmill walking at about 80% of the VO_2 max, sleep loss reduced work time to exhaustion by an average of 11%. This decrease occurred despite doubling monetary incentives for subjects during work after sleeplessness. Subjects appeared to fall into "resistant" and "susceptible" categories: four showed less than a 5% change in performance after sleep loss while four others showed decrements in exercise tolerance ranging from 15 to 40%. During walk, sleep loss resulted in significantly greater perceived exertion, even though exercise heart rate and metabolic rate were unchanged.

Findings suggest that the psychological effects of acute sleep loss may contribute to decreased tolerance of prolonged heavy exercise. Findings are consistent with those of another study by Martin (Martin and Gaddis, 1981).

Document No: 590

Title: THE EFFECT OF SLEEP LOSS ON HIGH INTENSITY EXERCISE AND RECOVERY

Authors: McMurray, R., and Brown, C.

Agency: University of North Carolina, Human Performance Laboratory

Dates: 1984

Tasks: Cardiovascular and metabolic responses, of subjects during submaximal exercise (80% VO_2 max) were examined after 24h of wakefulness. Exercise bouts lasted 20 minutes in run on motorized treadmill, interspersed with sleep or non-sleep night.

Subjects: 5 male subjects

Results: The loss of one sleep cycle does not alter resting physiological responses nor does it attenuate performance of 20 minutes of vigorous exercise. Exercise ventilation, heart rate, and oxygen uptake were not affected by sleep loss. However, sleep loss caused the recovery ventilation and oxygen uptake to remain higher than normal during the slow phase of recovery. Blood lactates were lower at the end of exercise after sleep deprivation and remained lower during the recovery period. Changes in plasma volume were not affected by sleep loss.

These results suggest that although sleep loss may not overtly affect acute submaximal exercise performance, it attenuates the recovery process.

Document No: 278

Title: FIELD STRESS: A PRELIMINARY STUDY OF STRUCTURE, MEASUREMENT,
AND RELATIONSHIP TO COMBAT

Authors: Meeland, Tor, Egbert, Robert L., and Miller, Irwin

Agency: U.S. Army Leadership, Human Research Unit, Ft. Ord.

Date: 1957

Stressors: Fatigue, lack of sleep, jump from tower, fighting oil
fires, simulated threats in darkness, distraction by explosives, electric
shock, simulated perimeter attack.

Task: Reaction time, tapping speed, 2-hand coordination

Subjects: 148 personnel in Basic Training without military
experience

Results: The cancelling C's test (a test of perceptual speed) was
administered after each threatening field situation. It was believed
that this test is a stress-sensitive measure; however, the test failed to
produce very striking or very informative results.

Document No: 268

Title: REVIEW OF LITERATURE ON THE EFFECTS OF SELECTED HUMAN
PERFORMANCE VARIABLES ON COMBAT PERFORMANCE

Authors: Michel, Rex R., and Solic, Robert E.

Agency: U.S. Army Research Institute for the Behavioral and Social
Sciences

Date: 1983

Stresses: Radiation illness
Combat stress
Fatigue

Tasks: Not applicable. This is a review article. The intent of the
review is to make modeling recommendations in support of the Army's Model
Improvement Program (AMIP)

Subjects: Soldiers in combat

Results: 35 articles and books on the problem of combat stress were
reviewed. Observations are made on the effects of intensity of combat,
duration of combat, type of combat, type of unit, unit cohesion, leader-
ship, personality and personal history, and weather. It is recommended
that AMIP incorporate combat performance degradation caused by stress
associated with combat intensity, combat type (fluidity of conflict, and
degree of success being achieved) and combat experience. Combat duration
effects should be considered if units will be modeled as operating con-
tinually in combat in excess of 5 days without replacements. It is
stated that neither the exact amount of performance degradations nor
proof of the nature of those degradations could be determined from the
review. Thus informed judgement will be required on the part of those
analysts attempting to include the influence of stress effects in AMIP
models (page 34).

60 publications dealing with the effects of fatigue were selected
for review because of their judged relevance to the military problem.
Little experimental work was found dealing with the influence of fatigue
on tactical decision making. However the authors state that performance
on more complex and absorbing tasks is more resistant to sleep deficit.
Historical evidence, mostly anecdotal, indicates that muscular fatigue,
sleep loss, and boredom are significant problems in a combat environment,
and that their effects are exacerbated by fear, physical discomfort, and
heat stress.

"Because of the task and situation-specific nature of fatigue ef-
fects and because of the interaction of fatigue with environmental stres-
sors, no data exist which would allow quantitative specification of fati-
gue effects in an aggregated model of combat performance despite a wealth
of data on specific tasks in non-combat situations."

Only qualitative findings were for the most part yielded by this literature review which were therefore regarded as suggestive rather than definitive regarding the impact of fatigue on the performance of individual tasks being performed within the context of continuous or nearly continuous combat operations. However, because of the lapse hypothesis and research conducted to prove or disprove its validity, it is stated that enough data are available to permit what are described as gross predictions regarding the impact of fatigue on particular kinds of combat activities. Predictions are gross in the sense of being totally qualitative, i.e., the impact on particular tasks was specified in terms of "small" or "large" and thus, quantitative baseline performance levels and estimates of "small" and "large" impacts must be developed before predictions will be of any great value for modeling purposes. (Page 41- 42).

These estimates of "large" and "small" were made for a number of combat model processes using a classification developed by VRI. They included, but were not limited to: maneuver unit combat, artillery fire, air to ground attacks, mobility, counter mobility, and survivability, communication, maneuver control, fire support allocation, resupply and placement, and movement. The coding reflected predicted degree of influence (large or small, considering the lapse hypothesis, previous data, and possible operational consequences; also taken into account was whether the activity is self paced or environmentally paced and whether the response is "automatic" or "considered."

Document No: 267

Title: EFFECTS OF CONTINUOUS WORK AND SLEEP LOSS ON THE RECOVERY OF SUSTAINED PERFORMANCE

Authors: Morgan Jr., Ben E., Coates, Glynn D., Brown, Bill R., and Alluisi, Earl L.

Agency: U.S. Army, Human Engineering Laboratory

Date: 1973

Stressors: Continuous work periods of 36 and 44 hours

Tasks: Multiple task performance battery (3 watchkeeping tasks, 3 active tasks related to memory functions, sensory-perceptual functions (target identification) and procedural functions (code-lock solving)

Subjects: 12 male college or university students

Results: The 36 hour continuous work period was associated with decrements of 14-18% in performance efficiency while the 44 hour period resulted in a decrement of about 22%. Following 36 hours of continuous work, two, three, and four hours of sleep yielded an immediate recovery in performance of about 76%, 56%, and 75% respectively, whereas four hours sleep following 44 hours of continuous work produced only 39% immediate recovery. It is suggested that 6-8 hours is the minimum amount of sleep required for the recovery of performance from the effects of 36 hours of continuous work and sleep loss.

Document No: 292

Title: EFFECTS OF CONTINUOUS WORK AND SLEEP LOSS IN THE REDUCTION AND RECOVERY OF WORK EFFICIENCY

Author: Morgan Jr., Ben B.

Agency: Performance Research Laboratory, University of Louisville

Date: 1974

Stressors: 36, 44, and 48 hours of continuous work and sleep loss

Tasks: Multiple task performance battery (See Morgan et al., 1973 (No. 267)).

Subjects: 10 male subjects assigned to two crews of 5 men each (presumably college students)

Results: 36, 44, and 48 hours of continuous work and sleep loss resulted in decrements in overall work efficiency of approximately 15%, 20%, and 35% respectively. Following 36 hours of continuous work, it was found that 12 hours of sleep is sufficient for complete recovery of performance, but complete recovery is not provided by 2 hours (58% recovery) 3 hours (53% recovery) or 4 hours (73% recovery) of sleep. It is indicated that the time course of recovery is different following different durations of continuous work and subsequent sleep.

Document No: 221

Title: COMBAT ENGINEER EFFECTIVENESS IN SUSTAINED OPERATIONS

Authors: Nyles, W. S., and Rommet, T.T.

Agency: Defense and Civil Institute of Environmental Medicine,
Ontario, Canada

Date : 1986

Stressors: Sleep deprivation for up to 69 hrs
Heavy physical work for up to 48 hrs
8 Km march
Forming abatises (felled trees across road)
Preparing mine fields
Cratering (digging)

Subjects: Four subjects from one combat engineering regiment, and 6
from another.

Results: The combat engineers were able to complete all the tasks assigned to them within the allotted 48 hours, although the times to complete individual tasks increased in the later stages. Sleep loss per se had no effect on self-paced work output as long as the soldiers were not physically fatigued. However, the authors suggest that even troops who receive at least four hours of dedicated sleep every night should not be considered immune to the effects of sustained operations. If the 20 waking hours were spent in prolonged fatiguing tasks, self-paced work output may still decline.

Document No: 305

Title: THE ROLE OF SLEEP DEPRIVATION RESEARCH IN HUMAN FACTORS

Authors: Naitoh, Paul and Townsend, Richard E.

Agency: Navy Medical Neuropsychiatric Research Unit, San Diego, CA,
and Dept. of Psychology, Duke University, Durham, North Carolina

Date: 1970

Stressors: Up to 171 hours of sleep deficit.

Subjects: Various groups of subjects, not described. The independent results from four separate studies are discussed.

Results: In one study, after 78 hours of sleep loss, mean visual reaction time was roughly twice as long as during a baseline period. Visual, auditory, and vibratory vigilance tasks showed the effects of sleep debt, particularly on more complex and tedious tasks. Sleep debt produced a significant increase in the number of errors of omission, i.e., lapses, in all vigilance tasks, indicating that the effects of sleep loss were not specific to a particular sense modality. In a 50 minute continuous counting task requiring continuous pressing of a keyboard assembly, subjects spent an average of 298 seconds less time at the task after one night of sleep loss than they did in a baseline period (only the first 30 minutes of the record were analyzed).

"Surprisingly good" tracking performance during a period of up to 171 hours of sleep deprivation was shown until sleep loss reaches 99 hours or more. (The tracking task was of 1 minute's duration on each of several pre-selected forcing function frequencies. The total task time is not reported, but apparently was very short).

Document No: 101

Title: EXTENDED HUMAN EFFECTIVENESS DURING SUSTAINED OPERATIONS
THROUGH SLEEP MANAGEMENT

Authors: Naitoh, P., Englund, C. E., and Ryman, D.H.

Agency: Naval Health Research Center, San Diego, CA

Date: 1983

Stressors: Two 20-hour periods of continuous work with either 0, 3, or 8 hours of sleep in between. Subjects worked physically at 30-40% of their maximal aerobic ability while performing various mental tasks

Subjects: 22 Marine Reconnaissance volunteers

Results: Physical work, in concert with sleep deprivation and continuous work, did not produce either statistically significant improvements or greater degradation of cognitive and physical task performance in comparison with sleep deprivation alone. When there was no sleep between the first continuous work period and the second, all cognitive performance tests showed significant decrements. Tasks included visual vigilance, simple reaction time, logical reasoning, 4-choice serial reaction time, auditory word memory, visual memory, and reading tests. A 3-hour nap taken between 0400 and 0700 was restorative of performance on some tasks but not others.

A three parameter sleep logistics model is suggested for the prediction of performance during continuous work periods. The three parameters are: (1) duration of the continuous work period; (2) duration of the nap; and (3) time of day when the nap is taken. The authors state that with this model the need for sleep among military personnel could be balanced against the need for effective manpower to maintain military operations for a successful outcome. Application of the model showed that a 2-hour nap taken between 0400 and 0600 after 20 hours of continuous work is estimated to extend human effectiveness by 4 hours beyond the normally expected time range, and a 4-hour nap by 12 hours.

Document No: 524

Title: WORK PRACTICES GUIDE FOR MANUAL LIFTING

Author: National Institute for Occupational Safety and Health

Agency: US Department of Health and Human Services,

Date: 1981

Tasks: The Guide summarizes a rich body of research and presents recommendations to control the various types of hazards associated with the unaided act of symmetric (two-handed) lifting of an object of known weight and size. Quantitative recommendations regarding the safe load weight, size, location and frequency of handling are presented.

Results: For the purpose of the Guide, a lifting task is considered to be the act of manually grasping and raising an object of definable size without mechanical aids (i.e., hoists, conveyors, block and tackle, etc.). The time duration of such an act is normally less than two seconds, and thus little sustained exertion is required (as opposed to holding or carrying activities). The lifting limits are intended to apply only for:

- a. smooth lifting
- b. two-handed, symmetric lifting in the sagittal plane (directly in front of the body; no twisting during lift)
- c. moderate width, e.g., 75 cm or less
- d. unrestricted lifting posture
- e. good couplings (handles, shoes, floor surface)
- f. favorable ambient environments.

The primary task variables include:

1. Object weight (L) - measured in kilograms
2. Horizontal location (H) - of the hands at origin of lift measured forward of the body centerline or midpoint between ankles (in centimeters).
3. Vertical location (V) - of the hands at origin of lift measured from floor level in centimeters.
4. Vertical travel distance (D) - from origin to destination of lift in centimeters.
5. Frequency of lifting (F) - average number of lifts per minute.
6. Duration or period - assumed to be occasional (less than one hour) or continuous (8 hours).

Two limits are provided based on epidemiological, biomechanical, physiological, and psychophysical criteria.

1. Maximum Permissible Limit (MPL)

This limit is defined to best meet the four criteria:

- a. Musculoskeletal injury rates and severity rates have been shown to increase significantly in populations when work is performed above the MPL.
- b. Biomechanical compression forces on the L₅/S₁ disc are not tolerable over 650 kg in most workers. This would result from conditions above the MPL.
- c. Metabolic rates would exceed 5.0 kcal/minute for most individuals working above the MPL.
- d. Only about 25% of men and less than 1% of women workers have the muscle strengths to be capable of performing work above the MPL.

2. Action Limits (AL)

The large variability in capacities between individuals in the population indicates the need for administrative controls when conditions exceed this limit based on:

- a. Musculoskeletal injury incidence and severity rates increase moderately in populations exposed to lifting conditions described by the AL.
- b. A 350 kg compression force on the L₅/S₁ disc can be tolerated by most young, healthy workers. Such forces would be created by conditions described by the AL.
- c. Metabolic rates would exceed 3.5 for most individuals working above the AL.
- d. Over 75% of women and over 99% of men could lift loads described by the AL.

The guideline is in the following algebraic form in metric units:

$$AL (Kg) = 40(15/H) (1-.004|V-75|) (.7+7.5/D) (1-F/F_{max})$$

$$MPL = 3 (AL)$$

where H = horizontal location (centimeters) forward of midpoint between ankles at origin of lift

V = vertical location (centimeters) at origin of lift

D = vertical travel distance (centimeters) between origin and destination of lift

F = average frequency of lift (lifts/minute)

F_{max} = maximum frequency which can be sustained

These variables are assumed to have the following limits.

1. H is between 15 cm and 80 cm. Objects cannot, in general, be closer than 15 cm (6 in) without interference with the body. Objects further than 80 cm cannot be reached by many people.
2. V is assumed between 0 cm and 175 cm representing the range of vertical reach for most people.
3. D is assumed between 25 cm and (200-V) cm. For travel less than 25 cm, set D = 25.
4. F is assumed between .2 (one lift every 5 minutes) and F_{max}. For lifting less frequently than once per 5 minutes, set F = 0.

The Guide does not address all MMH activities. Its primary focus is on lifting compact loads with both hands. For such work, it represents the current state of the art in risk control, and presents a useful starting point to deal with complex problems presented by other manual materials handling tasks.

Document No: 199

Title: THE EFFECTS OF ACUTE SLEEP DEPRIVATION ON SELECTIVE ATTENTION

Author: Norton, Royau

Agency: Department of Clinical Psychology, Kingseat Hospital, Newmachar, Aberdeenshire, U.K.

Date: 1970

Stressors: No sleep for 96 hours

Subjects: 16 university students, 8 males and 8 females

Results: Performance was measured on a card sorting task, where the cards had various amounts of irrelevant information that had to be discriminated (ignored). It was shown that when the task included irrelevant information performance deteriorated more after sleep loss than it did on the same task without irrelevant information present. The author suggested that sleep plays an important part in maintaining selective attention and the symptoms shown by sleep deprived subjects are largely due to a failure in selective attention. The author feels that a breakdown in the selective function of attention is an important factor in deterioration due to sleep deprivation and could in fact account for a large proportion of the deterioration caused by sleep deprivation.

Document No: 168

Title: RESEARCH ON BEHAVIOR IMPAIRMENT DUE TO STRESS: AN EXPERIMENT
IN LONG-TERM PERFORMANCE

Author: Orr, David B.

Agency: American Institutes for Research, Washington, DC

Date: 1964

Stressors: 21 hours continuous performance in an aircrew simulator

Tasks: Complex eye-limb coordination
Problem solving
Estimating closure rates
Vigilance

Subjects: Two Air Force reserve officer training corps students

Results: Major performance decrements occurred for most of the tasks. Steep drop offs in vigilance task performance after 10 hours. Progressive deterioration in directional control and complex coordination.

Document No: 495

In Salvendy, Gavriel and Smith, M.J. (Eds.) Machine Pacing and Occupational Stress, Taylor and Frances, Ltd., London, 1981.

Title: THE MECHANISM OF MENTAL FATIGUE

Author: Oshima, Masamitsu

Agency: Medical Information System Development Center, Akasaka, Minato-Ku, Tokyo, Japan. 1981.

Date: 1981

Stressors: Continuous work; several different studies.

Subjects: 9 truck drivers, 4 undescribed, 1 office worker, undescribed number of bicyclists, 12 waterpower workers.

Tasks: Various. Truck driving, riding motorbike or bicycle.

Results: This is a summary of several studies conducted by the author. Data are presented indicating that critical flicker frequency (CFF), the frequency at which an intermittent light appears to be a steady beam, declines as a function of the length of time working. The author considers CFF to be a direct index of mental fatigue. No other research is cited by the author to support this assertion.

Research by others (e.g., Grandjean, et al. 1977) has shown that trends in CFF with work time depend on the nature of the task being performed and, most particularly, the mental load involved. It should be cautioned, therefore, that models such as the MOS-IV mental fatigue model developed for the Army Research Institute, which is described as reflecting the work of Oshima in particular, may involve an inappropriate generalization to many Army task situations.

Document No: 442

Title: THE PSYCHOLOGICAL EFFECTS OF 205 HOURS OF SLEEP DEPRIVATION

Authors: Pasmann, Robert O., Naithon, Paul, Stier, Serena, and Kollar, Edward J.

Agency: Neuropsychiatric Institute, School of Medicine, University of California, Los Angeles

Date: 1968

Stressor: 205 hours without sleep

Tasks: Similarities and Logical Puzzles Tests; Short term memory test; Interaction test (group problem solving without verbal communication); Visual-Motor tracking task

Subjects: 4 healthy young males

Results: Reading was impossible after the 3rd day. The hours between 2 AM and 6 AM were extremely difficult. After the 4th day each subject developed doubts about the others' capability to continue. The 5th day saw a "turning point" where subjects seemed to reach the bottom of their coping abilities and then level off or even improve somewhat.

Sleep deprivation evidenced itself in disruption of group cohesiveness, increased irritability and anger, marked increase in misperceptions and illusions. Brief intrusions of sleep with the eyes open occurred, followed by abrupt return to alertness. Great difficulty was experienced in keeping subjects awake starting on the 4th and 5th days. Regressive (infantile) behavior occurred during the last 3 days, including one emotional breakdown.

The tracking task showed only modest deterioration for the first 4 days, followed by marked increase in errors on 5th and 6th days. At 200 hours even the simplest tracking task was impossible.

The tests of thought processing (puzzles and similarities) showed no deterioration until after 150 hours of sleep deprivation when there was a shift toward "more childlike" levels of cognition. There was no change in short term memory scores between 100 and 200 hours of sleep deprivation, when there was a sharp drop in correct responses. (Unfortunately, this test was not started until after 100 hours of sleep deprivation had been experienced). Group problem solving at the end of this experiment was at the same level as at 50 hours except for increased time per trial. We are not told how the group performed when fresh.

Measures of "visual misperception", temporal disorientation, and cognitive disorganization increased steadily from about the 60th hour to the 180th hour, after which no data are presented.

It is unfortunate that this remarkable study did not employ a series of operationally meaningful performance tasks, given frequently throughout the experiment.

Document No: 235

Title: FATIGUE STRESSORS IN SIMULATED LONG-DURATION FLIGHT. EFFECTS ON PERFORMANCE, INFORMATION PROCESSING, SUBJECTIVE FATIGUE, AND PHYSIOLOGICAL COST

Author: Perelli, Layne P.

Agency: U.S.A.F. School of Aerospace Medicine

Date: 1980

Stressors: Two 4.5 hour flights per day; 12 hour duty days for 4 consecutive days

Tasks: Flying a link trainer
Discrete information processing (5-choice adaptive reaction time task)

Subjects: 24 airmen

Results: All measures of flight performance showed significant fatigue effects, and there were circadian effects as well. The threshold for information processing increased with fatigue. The fatigue effects were seen even though all subjects apparently got a reasonable amount of sleep, i.e., the schedule permitted considerably more sleep than would continuous operations.

Document No: 447

Title: FATIGUE IN SUSTAINED TACTICAL OPERATIONS

Author: Peterzen, Peter B.

Agency: The George Washington University

Date: 1972

Stressors: Military Operations in Vietnam

Task: Not applicable. Soldiers completed a questionnaire measuring basic beliefs, activity preferences, personal values, and behavioral styles. This was done while in a combat environment and again, later, after return to U.S.

Subjects: Two large groups of enlisted infantrymen assigned to rifle companies in Vietnam

Results: Several significant shifts in attitudes of infantrymen from those held in Vietnam to those held after return to U.S. were identified.

The author makes frequent reference to the importance of fatigue in sustained tactical operations. He suggests (without data) several leadership techniques for coping with fatigue in combat. In all, the data and procedures used in this study have little, if anything, to do with its title or its Executive Summary. Unfortunately, there is no connection made between the attitude measures taken and any assessment of the fatigue or the performance of the soldiers.

Document No: 570

Title: METABOLIC MEASURES TO ASCERTAIN THE OPTIMAL LOAD TO BE CARRIED BY MAN

Authors: Pierrynowski, M., Winter, D., and Norman, R.

Agency: University of Waterloo, Department of Kinesiology for Defense and Civil Institute of Environmental Medicine

Date: 1981

Hypothesis: Optimum load depends on whether the subjects are given credit for carrying only the load, for carrying their body mass plus the load, or given only partial credit for carrying their own body mass.

Stressors: Six loads (0.0, 15.16, 19.30, 22.65, 28.63, and 33.85 kg) were examined. The load device was a conventional frame and hip belt. Subjects were required to stand still, holding the external load for 12 minutes, and then required to walk on a treadmill at a fixed velocity for 12 minutes/load, with 10 minute rest periods.

Tasks: Treadmill walk at fixed pace with and without load.

Subjects: Six healthy male university subjects.

Results: If the load were body plus backpack, the optimal backpack load was found to be less than 10 kg because the metabolic cost increased rapidly at low loads. If the carrier's mass (72 kg walking at 5.54 mph) was ignored there might be an optimum load at 40 kg or higher. Giving partial credit for carrying body weight resulted in an optimum load of about 17 kg. The percentage credit given to the body mass itself depends on how important it is that the carrier does not arrive fatigued at his destination. The military may wish to give 100%.

Document No: 304

Title: PHYSICAL FITNESS AS A MODERATOR OF COGNITIVE WORK CAPACITY
AND FATIGUE ONSET UNDER SUSTAINED COMBAT-LIKE OPERATIONS

Authors: Pleban, R.J., Thomas, D.A., and Thompson, H.L.

Agency: U.S. Army Research Institute, Ft. Benning, GA and U.S. Army
Command and General Staff College, Ft. Leavenworth, KS

Date: 1985

Stressors: 2 days of participation in patrol missions, and conducting raids and ambushes. Sleep limited to approximately 2 hours.

Subjects: Applicants for Ranger training

Results: Cognitive performance was assessed using three paper and pencil tests: (1) logical reasoning test; (2) map plotting test; and (3) encoding-decoding test. Fitness was assessed on the basis of a composite score on five indices: chin ups; push ups; sit ups; 2-mile run, and pulse rate during the Harvard step test. Evidence of a positive effect of fitness on cognitive work was strongest in the encoding-decoding task where the authors conclude that fitness began to assert a beneficial influence when the cognitive task or activity was relatively sustained in nature (six minutes or longer) and as the cumulative effects of sleep loss and other stressors began to mount. However fitness did not significantly enhance the recovery process with respect to cognitive work capacity, and actually appeared to hinder recovery from fatigue in this respect.

Document No: 261

Title: THE EFFECTS OF SLEEP DEPRIVATION ON PERFORMANCE IN A
SIMULATED COMMUNICATION TASK

Author: Schein, Edgar H.

Agency: Walter Reed Army Institute of Research

Date: 1957

Stressors: 55-70 hours of sleep loss

Subjects: 20 volunteers from a medical research unit, not otherwise described. Since the group was fulfilling its military obligation by volunteering for medical research studies, it was considered to be composed of very highly motivated individuals.

Results: Performance was measured on ability to receive and send complex instructions, which were thought to involve functions of importance in real life situations like combat. The subjects were required to discover a correct pattern (layout) of domino-like pieces solely on the basis of received (or sent) verbal instructions. The data suggested that the subjects were continuing to learn this task despite some performance decrements during extended periods without sleep. The decrement in receiving was significant but the decrement in sending was not. (11% vs. 7% and 6%). The time required by subjects to send their instructions showed a progressive increase during the experimental condition, being 26% and 33% longer than during the pre-deprivation period. After 70 hours of sleep loss, subjects found it necessary to correct 170% and 127% more errors than in the pre-deprivation period.

The author felt that the amount of decrement shown during sleep deprivation was surprisingly small and noted that even after 55 hours without sleep, some subjects performed almost at their pre-deprivation level. However, the subjects were tested only twice during the entire deprivation period, and task learning may well have been a factor. Test durations were not stated but involved only 10 problems, which probably accounts for the relatively small, though significant increases in errors. The author concluded that performance begins to decline at 55 hours without sleep, but it should be noted that no performance measures were taken prior to the 55 hour point in the experiment.

Document No: 539

Title: THE EFFECTS OF HEAT STRESS ON MANUAL HANDLING TASKS

Authors: Snook, S. and Ciriello, V.

Agency: Liberty Mutual Insurance, Co.

Date: 1974

Stressors: Tasks were performed in a moderate environment (WBGT of 17.2 degrees C and in a hot environment (27 degrees C). Subjects received one 3hr, 10min exposure per week, with test sessions conducted in the morning on weekdays.

A psychophysical methodology was used whereby the workers controlled their own work load by adjusting the frequency of the task or the weight of the object being handled.

Tasks: Workers performed three basic manual material handling tasks - lifting, pushing, and carrying.

Subjects: 16 male industrial workers, unacclimatized to heat.

Results: The hot environment significantly reduced work load, significantly increased heart rate, and significantly increased rectal temperature for all three tasks (lift, pull, and carry). Work load was reduced by 20% for lifting, 16% for pushing, and 11% for carrying. Heart rate responded with a consistent rise for all three tasks. Energy expenditure was also lower in the hot environment, but the decrease was significant for lifting and pushing only.

When unacclimatized man manually handled materials at a self-pace, he compensated for increases in heat stress by reducing his work load. The amount of reduction in work load appeared to vary depending on the levels of heart rate and rectal temperature.

Document No: 518

Title: MAXIMUM FREQUENCY OF LIFT ACCEPTABLE TO MALE INDUSTRIAL WORKERS

Authors: Snook, S. H., and Irvine, C. H.

Agency: Liberty Mutual Insurance, Co.

Date: 1968

Stressors: Repetitive lifting over a range of tote box weights and heights. Weights of 35 and 50 lb; lift height of floor level to knuckle height, knuckle height to shoulder height, and shoulder height to arm reach. Actual experimental trial ran 1 hour, and was replicated 3 times with 15 minute breaks between sessions.

Task: Lift tote box to simulate repetitive lifting over an 8 hour day.

Subjects: 8 healthy, conditioned males from local industry.

Results: Significant differences existed in workload (foot-pounds per minute) among the three heights and two weights. Workload guidelines are given for 10, 25, 50, 75, and 90% of the healthy male industrial population for lifting at the three heights. For 90% of the population, at object weights from 35 to 50 lbs, the workload at the low lift is below 200 ft-lb/min; at mid height, the workload is roughly 300 ft-lb/min; at the upper height, the workload is about 250 ft-lb/min.

Document No: 574

Title: ENERGY COST OF LOADS CARRIED ON THE HEAD, HANDS, OR FEET

Authors: Soule, R., and Goldman, R.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1969

Stressors: Treadmill walking for 20 minutes, at 3 speeds, with load.

Subjects: 10 volunteer subjects

Tasks: Marching with load.

Results: Load location significantly affected the resulting energy cost, expressed per kilogram of total weight (man+clothing+load).

The cost per kg of weight carried on the head was 1.2 times the expected cost per kg of the no load condition at all speeds.

The cost for carrying load in the hands increases as the speed increased, by 1.9 times the no load cost at 5.6 km/hr over the 4 and 7 kg loads. At slower speeds the cost for the 7 kg load was also 1.9 times the no load cost.

The cost per kg of load carried on the feet (e.g., due to spike-proof boots, weighted innersoles, etc.) was 4.2 times the no load cost per kg at 4.0 km/hr, 5.8 times at 4.8 km/hr and 6.3 at 5.6 km/hr. This could prove to be rate limiting. At 6 kg load, the energy costs were close to maximum $\dot{V}O_2$.

Document No: 571

Title: ENERGY EXPENDITURE OF HEAVY LOAD CARRIAGE

Authors: Soule, R., Pandolf, K. and Goldman, R.

Agency: US Army Research Institute of Environmental Medicine,
Natick, MA

Date: 1978

Stressors: Loads ranged to 50 kg in the first study, carried for 20 minutes. Loads in second study were heavier, fit to the physical limits of the subject, and were carried for longer periods. Up to 30 kg was placed evenly around the waist in pouches on a standard web belt.

Tasks: Treadmill walking, with load, at range of speeds.

Subjects: 24 subjects over two studies.

Results: After deducting the individual's no load cost, the resulting net energy expenditure for carrying the loads was generally constant at each speed, i.e., loads from 35 to 70 kg showed no statistical differences in energy expenditure per kg at 3.2 and 4.8 km/hr. At 6.4 km/hr carrying 70 kg the average measured cost per kg was statistically different than carrying 35 kg at this speed. Subjects were working at greater than 90% of their maximal $\dot{V}O_2$ carrying 70 kg. The general constancy of measured energy expenditure per kg for loads even up to 70 kg probably depends on the condition that the load is well balanced and close to the center of the body. Higher costs are associated with loads in unbalanced positions. Thus, the limitations commonly encountered in load carrying capacity may arise from poor positioning of the load rather than from the weight of the load per se.

Document No: 324

Title: THE FIELD ARTILLERY FIRE DIRECTION CENTER AS A LABORATORY AND FIELD-STRESS PERFORMANCE MODEL (IN AGARD CONFERENCE PROCEEDINGS, NO. 180)

Authors: Stokes, J.W., Bandaret, L.E., Francesconi, R.P., Cymerman, A. and Sampson, J.B.

Agency: U.S. Army Institute of Environmental Medicine, Natick, Mass.

Date: 1976

Stressors: Disrupted sleep-rest schedules; high altitude conditions (achieved using hyperbaric chamber); 48-hours of continuous performance

Subjects: 6 volunteers from a 105mm howitzer battery of an elite Army Airborne Unit

Tasks: All tasks associated with the field Fire Direction Center (FDC) using realistic combat scenarios

Results: (Authors' summary): The 5-man fire direction center (FDC), common to all Field Artillery batteries, was chosen for study in the laboratory and field to evaluate the impact of environmental and situational stress on the complex performance of highly trained and motivated individuals working together as a team. The working environment of a field FDC was simulated within a hypobaric chamber and a volunteer FDC team from an elite U.S. Army unit was tested using realistic matched "combat" scenarios. To minimize practice effects, the team was initially given 26 h of "intensified training" (ITS). The team was then tested single-blinded as to the altitude condition for 48 hours at both 427 m (control) and 4242 m; the team rested 22 h between ITS and control and 48 h between control and the high altitude conditions. Mission performance during ITS and control was sensitive to disrupted sleep-rest cycles, with errors clustering at times of low arousal. At high altitude, performance was less efficient during the first 10 h; most serious errors involved processing of digits. Overlearned FDC skills showed little deterioration even when the men were ill with acute mountain sickness; compensatory behaviors were evident and technical performance for the last 38 h at altitude equaled or exceeded control. Thus, in this study communications, psychomotor, and judgement aspects of FDC performance, as well as measures of symptoms, mood, and neuroendocrine response, appear differentially sensitive to psychological stress, hypoxia, and fatigue. The rationale and objectives of this program are given (Part I) as well as initial experimental results (Part II).

Document No: 214

Title: THE EFFECTS OF STRESS ON THE PERFORMANCCE OF RIFLEMEN (U)

Authors: Torre Jr., James P., and Kramer, Richard R.

Agency: U.S. Army Human Engineering Laboratories

Date: 1966

Stressor: Targets on range firing back (BB shots)

Task: Quick fire of M14 and M16 rifles at pop-up targets

Subjects: 60 infantrymen

Results: Under the stress condition subjects fired more rounds and got lower hit to shot ratios. They got fewer first round hits as well.

Document No: 088

Title: MODEL EFFECTIVENESS AS A FUNCTION OF PERSONNEL

Author: Van Nostrand, Sally J.

Agency: U.S. Army Concepts and Analysis Agency

Date: 1986

Stressors: Length of continuous operations
Heat
Sustained operations
(These stressors are considered in combination)

Subjects: Soldiers in general. This was a study aimed at identifying those areas in which the modeling of battlefield processes could and should be modified to include the effects of human factors and human performance.

Results: The project demonstrated that human data can make large differences in combat results and that the Force Evaluation Model (FORCEM) could be modified to reflect the detrimental effects of environment and stress on humans. It was concluded that sufficient human performance data do exist to develop a data base that includes both equipment and human data for parameters such as probability of detection and probability of hit.

Document No: 493

Title: TRASANA ANALYSIS IN SUPPORT OF THE MANAGEMENT OF SLEEP AND STRESS IN CONTINUOUS OPERATIONS (MOSSICO) STUDY. (DISTRIBUTION OF THIS REPORT IS LIMITED)

Authors: Not identified

Agency: U.S. Army TRADOC Systems Analysis Activity

Date: 1985

The MOSSICO study had, as one of its major objectives, quantification of the effects of changes in individual combat effectiveness due to loss of sleep and stress by interfacing results of the PERFECT model (see Siegel et al, Document No. 181), which generates estimates related to individual soldier performance, and the AMORE model, which simulates unit capability.

It was concluded that the interface as originally envisioned was not possible because the AMORE model outputs unit capability, not effectiveness. However, a limited study was accomplished of personnel transfer times. This reflects situations in which personnel can transfer to other positions in a unit because of cross-training or similarity of skills. Personnel transfer times were increased to model the effects of loss of productivity due to continuous operations.

The outputs of the PERFECT model were not used; rather an unexplained "Productivity Index" was used that generated increased transfer times for different personnel categories depending on whether their jobs were mainly Cognitive, Cognitive-Physical, or Physical, and whether they belonged to a Mechanized Infantry Company, Tank Company, or Howitzer Battery. Outcomes reflect the amount of delay in recovery of the unit due to the increased transfer times.

The assumptions made about the effects of sleep loss on performance are not made explicit in this report, making it difficult to evaluate. However, the concept that transfer time affects unit recovery time may prove useful.

Document No: 304

Title: EXPERIMENTS ON EXTENDED PERFORMANCE: REPETITION, AGE, AND LIMITED SLEEP PERIODS

Author: Webb, Wilse B.

Agency: University of Florida, Gainesville

Date: 1985

Stressors: 60 hours of sleep deprivation with a maximum of 4 hours of sleep. (Three different time periods were used).

Subjects: An unstated number of college students aged 18-22 years; 10 faculty members aged 40-50 years of age; and 12 faculty members aged 50-60 years of age. A central interest of this study was in the effects of sleep deprivation on older personnel, approximating the age of military commanders.

Results: Performance was measured in auditory vigilance, addition, word memory, word detection, visual search, logical reasoning, remote associates, and others. It was concluded that older subjects in the age range of 40-60 years, tended to be more vulnerable to sleep deprivation effects than were younger subjects. However, the differences were not substantial. The presence of 4 hours of sleep in three different schedules revealed only limited differential ameliorative effects in reducing the performance decrements.

It should be noted that the performance periods in this study were of three hours' duration and were discontinuous, with only three performance periods per 24 hours. Additionally, there were three 1-hour meal periods interspersed in the 24-hour cycle.

Document No: 284

Title: A STUDY OF SOME DETERMINERS OF PSYCHOLOGICAL STRESS

Authors: Wherry Jr., Robert J., and Curran, Patrick M.

Agency: U.S. Naval School of Aviation Medicine, Pensacola

Date: 1965

Stressor: Electric shock

Task: Performing a four choice color discrimination task at maximal rate (self paced). The study was designed so that it dealt with the stress associated with anticipating a physical threat.

Subjects: 64 Naval and Marine Corps cadet pilot trainees.

Results: Performance deteriorated: (1) as the threatening event came closer in time; (2) as the perceived probability of shock increased; and (3) as the perceived degree of unpleasantness increased. There was some support for the inverted U hypothesis. The model in Figure 1, though not reproduced here, is of interest.

Document No: 464

Title: THE EFFECTS OF SLEEP LOSS ON PERFORMANCE

Author: Wilkinson, R.T.

Agency: Medical Research Council, Applied Psychology Research Unit,
Cambridge, England

Date: 1958

Stressor: 26-30 hours of sleeplessness

Tasks: Card sorting, forward and backward writing, note learning, vigilance (detection of target signals on a screen), addition, serial reaction time (regarded as a decision-making task). The longest task (vigilance) was of only 40 minutes duration.

Subjects: Royal Navy enlisted personnel (up to 16 per test condition)

Results: In a number of short tasks lasting less than 10 minutes no significant decline in efficiency was found following sleep loss. In the vigilance and decision making tasks, pronounced declines were observed but not until at least 10 minutes had been spent at the task. Some "more complex" tasks such as addition showed no decline even after 25 minutes.

Performance feedback appeared to substantially reduce the sleep loss effects. It is suggested that "the less predictable the sleeploss operator finds the task situation, and the greater the penalty he suffers for failing to predict it accurately, the less likely is his efficiency to fall below normal levels".

A tentative conclusion from the vigilance experiments may be of special interest. "Where a repetitive routine response pattern has to be discontinued and replaced by other responses appropriate to a sudden and perhaps critical change in the situation, sleep loss may reduce the speed with which this transition is made; still worse an error may result if the first inadvertent response cannot be rescinded.

Document No: 200

Title: THE EFFECT OF LACK OF SLEEP ON VISUAL WATCH-KEEPING

Author: Wilkinson, R. T.

Agency: Medical Research Council, Applied Psychology Research Unit,
Cambridge

Date: 1960

Stressors: Loss of one nights sleep

Tasks: Visual vigilance detecting infrequent spots of light presented on glass screen over a 40-minute period

Subjects: Naval ratings between the ages of 18-30. The number was not specified, but was apparently 15.

Results: Subjects who had no sleep the previous night maintained performance on the vigilance task for the first 20 minutes of the test at a level comparable to a control condition where normal sleep was permitted. After 20 minutes however, the rate of signal detection declined steadily. In the final quarter of the test, the detection rate was roughly 1/3 that of the first quarter.

The signals that were missed were divided into three categories: (a) those missed while watching the display; (b) those missed while not watching; and (c) those missed while asleep. Lack of sleep produced increases in all three of these categories. The author concludes that the results support previous suggestions that a test has to be prolonged before performance is affected by moderate loss of sleep.

Document No: 297

Title: SOME EFFECTS OF SLEEP LOSS ON MEMORY

Authors: Williams, Harold L., Gieseeking, Charles F., and Lubin, Ardie

Agencies: University of Oklahoma School of Medicine; Walter Reed Army Institute of Research; U.S. Navy Medical Neuropsychiatric Research Unit, San Diego

Date: 1966

Stressors: One nights sleep loss

Tasks: Recall of lists of words; recognition of pictures of faces

Subjects: 44 U.S. Army enlisted male volunteers

Results: Immediate recall of word lists showed significant impairment after one night of sleep loss. However the picture recognition test did not show significant deficit after one nights sleep loss. Performance on this test was impaired however, after a night of recovery sleep. The authors conclude that moderate sleep loss causes deficit in formation of the memory trace rather than in storage or retrieval functions and that this effect is probably independent of the physiological lapses (brief periods of sleep) which affect vigilance and sensory registration.

APPENDIX C
ANNOTATED BIBLIOGRAPHY

- Aberg, U., Elgstrand, K., Magnus, P., and Lindholm, A. (1968). Analysis of components and prediction of energy expenditure in manual tasks. Intl. J. Prod. Resch., 6(3), 189-196.
- Abram, Harry S. (Ed.). (1970). Psychological Aspects of Stress. Charles C. Thomas. Springfield, Illinois.
- Abramowitz, Jeff. (1988, January 16). Motivation: What makes a soldier fight? Jane's Defense Weekly.
- Adams, Mario A. (1985, December). TRASANA (Army TRADOC Systems Analysis Activity) Analysis in Support of the Management of Sleep and Stress in Continuous Operations ((MOSSICO) Study). White Sands Missile Range, NM: Army Tradoc Systems Analysis Activity.
- Ainsworth, L.L. and Bishop, H.P. (1971, July). The Effects of a 48-Hour Period of Sustained Field Activity on Tank Crew Performance. (Hum-RR0 Technical Report 71-16). Alexandria, VA: Human Resources Research Organization. (Full Synopsis in Appendix A).
- Alkov, Robert A., Gaynor, John A., and Borowsky, Michael S. Pilot Error as a Symptom of Inadequate Stress Coping. Aerospace Medical Association.
- Task: Aircraft piloting (accident involvement).
Stressors: Various life circumstances.
Notes: Focus on life stresses that may contribute to individual differences in culpability in major aircraft mishaps.
- Alkov, Robert A., Borowsky, Michael S., and Gaynor, John A. Stress Coping and the U.S. Navy Aircrew Factor Mishap. Norfolk, VA: Naval Safety Center, Naval Air Station.
- Task: Flying Navy aircraft.
Stressors: Personal life events.
Notes: Personal life stresses - not a variable we can deal with in model.
- Allen, T.W., Johnson, E. III, Wheaton, G.R., and Knorr, C.M. (1982, March). Methods of Evaluating Tank Platoon Battle Run Performance: Design Guidelines. ARI Technical Report 569, (AD131969).
- Task: Engage tank platoons in battle runs; measure and assess performance.
Stressors: None - not applicable.
Notes: Guidebook aimed at battalion S-3 and his OIC for assessing tank platoons. Provides inventory of tasks & evaluative performance standards.

Allnutt, N.F. Sleep at Unusual Hours, Drugs, and Subsequent Performance. In A.J. Benson (Ed) AGARD Proceedings No. 74: Symposium on Rest and Activity Cycles for the Maintenance of Efficiency of Personnel Concerned with Military Flight Operations.

Alluisi, E.A., and Chiles, W.D. (1967). Sustained Performance, Work-rest Scheduling, and Diurnal Rhythms in Man. Amsterdam: North-Holland Publishing Co.

Alluisi, E.A., Chiles, W.D., and Smith, R. (1964, August). Human Performance in Military Systems: Some Situational Factors Influencing Individual Performance. (Interim Technical Report 64-1). Louisville, KY. Performance Research Lab., Dept. of Psychology, Univ. of Louisville.

Task: General military - a review article.

Stressors: Atypical work - rest schedule; LSD ingestion.

Notes: No data.

Angus, Robert G., Haselgrave, Ronald J. (1983). The effects of sleep loss and sustained mental work: Implications for command and control performance. In AGARD Conference Proceedings No. 338. Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Message processing, reaction time, subtraction, encode/decode, logical reasoning, ST memory, vigilance.

Stressors: 54 hours of continuous work.

Notes: Same study as Angus and Haselgrave, 1985.

Angus, Robert G., Haselgrave Ronald J. (1985, February). Effects of sleep loss on sustained cognitive performance during a command and control simulation. Psychonomic Society, Inc. In Behavior Research Methods, Instruments & Computers, 17(1). (Full Synopsis in Appendix A).

Appley, M.H. (1966, June). Conference on Psychological Stress. Final Report to ONR, (AD634880). Toronto, Canada: York University.

Task: None - this paper simply lists the conference participants. Proceedings published separately in Psychological Stress: Issues in Research Appleton-Century-Crofts, 1966.

Arborelius, Ulf.P., Ekholm, J., Nemeth, G., Svensson, O., and Nisell, R. (1986). Shoulder joint load and muscular activity during lifting. Scand. J. Rehab. Med., 18(2), 71-82.

Arendt, J., Aldhous, M., English, J., Marks, V., and Arendt, J.H. (1987). Some effects of jet-lag and their alleviation by melatonin. Ergonomics, 30(9), 1379-1393.

Arima, J.K. (1967). Human Factors in Weapon System Evaluation. (Tech Paper LSSL-TP-69-1). Ft. Ord, CA: Behavioral & Life Sciences Section, Mellonics Systems Dev. Div. Litton Scientific Support Lab.

Artiss, K.L. (1963). Human Behavior Under Stress - From Combat to Social Psychiatry. Military Medicine, 128, 1011-1015.

Stressors: Combat.

Notes: No primary data except for casualty data.

Asfour, S.S., Ayoub, M.M., and Mital, A. (1984). Effects of an endurance and strength training programme on lifting capability of males. Ergonomics, 27(4), 435-442.

Babkoff, H., Thorne, D.R., Sing, H.C., Genser, S.G., Taube, S.L., and Hegge, F.W. (1985). Dynamic changes in work/rest duty cycles in a study of sleep deprivation. Psychonomic Society Inc: Behavior Research Methods, Instruments & Computers, 17, 604-613.

Baddeley, A.D. (1972). Selective Attention and Performance in Dangerous Environments. British Journal of Psychology, 63, 537-546.

Stressors: Diving, parachute jumping, threat of fire.

Notes: Useful in terms of general effect on the narrowing of attention.

Baker, R.A., Wars, J.R., & Sipowicz, R.R. (1962). Sustained vigilance: I. Signal detection during a 24-hour continuous watch. Psychol. Rec., 12, 245-250.

Baker, Robert A. (1958, May). The Determination of Job Requirements for Tank Crew Members. (Technical Report 47). Ft. Knox, KY: U.S. Army Armor, Human Research Unit.

Baker, Robert A., Mathers, Boyd L. and Roach, Eugene G. (1959, June). The Effects of Increasing and Decreasing Training Time on Proficiency in the Critical Armor Skills. (Technical Report 55). Ft. Knox, KY: U.S. Army Armor, Human Research Unit.

Bandaret, L.E., Stokes, J.W., Francesconi, R., Kowal, D.M. & Naitoh, P. (1981). Artillery teams in simulated sustained combat: performance and other measures. In NIOSH Proceedings, The 24-hr Workday (Pub. No. 81-127, pp. 581-604). Cincinnati, OH: U.S. Dept. of Health & Human Services.

Banderet, L.E., and Stokes, J.W. (1980). Simulated Sustained Combat Operations in the Field Artillery Fire Direction Center (FDS): A Model for Evaluating Biomedical Indices. (Full Synopsis in Appendix A).

Banks, J.H., Sternberg, J.J., Farrell, J.P., Debow, C.H., and Dalhamer, W.A. (1970). Effects of Continuous Military Operations on Selected Military Tasks. (ARI Technical Research Report 1166). Alexandria, VA: US Army Research Institute for the Behavioral and Social Sciences. (Full Synopsis in Appendix A).

Barron, R.C., Lutz, W.G., Degelo, G.J., Havens, J.W., Talley, J.W. (1976, September). Degradation of Tank Effectiveness. Fort Hood, TX: TRADOC Combined Arms Test Activity. (Abbreviated Synopsis in Appendix B).

Bartemeier, L.H., Kubie, Lawrence, S., Menninger, Karl A., Romano, John, and Whitehorn, John C. (1946). Combat Exhaustion. J. Nerv. Ment. Dis., 104, 358-524.

Stressors: Combat.
Notes: Entirely clinical.

Bartlett, F.C. (1941). Fatigue following highly skilled work. Proceedings of the Royal Society of London. Series B. Biological Sciences, 131, 247-257.

Baum, Andrew, Singer, Jerome E., and Baum, Carlene S. (1981). Stress and the Environment. Journal of Social Issues, 37, 1.

Notes: Strictly review article with sociopsychological bent.

Beare, A.N., Bondi, K.R., Biersner, R.J., & Naitoh, P. (1981). Work and rest on nuclear submarines. Ergonomics, 24, 593-610.

Task: No performance measures.
Stressors: Confinement in submarine. (No severe sleep loss).
Notes: Averaged 8 hrs sleep in 24.

Beaumont, R.A., and Snyder, W.P. (1980). Combat Effectiveness: Paradigms and Paradoxes. In S.D. Sarkesian (ed.), Combat Effectiveness: Cohesion, Stress and the Volunteer Military. Beverly Hills, CA: Sage.

Beebe, Gilbert W., and Appel, John W. (1958). Variation in Psychological Tolerance to Ground Combat in World War II. Washington: National Academy of Sciences, Nat'l Res. Council, Div. of Medical Sciences.

Behar I., Kimball, K.A., & Anderson, D.A. (1976). Dynamic visual acuity in fatigued pilots. Fort Rucker, AL: U.S. Army Aeromedical Research Lab.

Belenky, Gregory., Balkin, Thomas, Krueger, Gerald, Headley, Don., Solick, Robert. (1986, October). Effects of continuous operations (CONOPS) on soldier and unit performance. Phase I Review of the Literature. Ft. Leavenworth, KS: US Army Combined Arms Combat Developments Activity. (Full Synopsis in Appendix A).

Belenky, Gregory L., Krueger, Thomas J., Balkin, Thomas J., Headley, Donald B., and Solick, Robert E. (1987). Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance: Review of the Literature and Strategies for Sustaining the Soldier in CONOPS. Walter Reed Army Institute of Research. (Full Synopsis in Appendix A).

Bell, C. and Crowder, M. (1971). Durations of safe exposure for men at work in high temperature environments. Ergonomics, 14(6), 733-757. (Abbreviated Synopsis in Appendix B).

Benson, A.J., (Ed.) (1970). Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations. Proceedings of the NATO advisory group for Aerospace R&D (AGARD) Aerospace Medical Panel Specialists' Meeting at Oslo, Norway. (AGARD Proceedings No. 74).

Task: Various - flying and air traffic control.

Stressors: Multiple time zones, extended operations, high workload.

Notes: Results of an AGARD symposium with emphasis on work-rest cycles of aircrew & air traffic controllers. Even with double crews, it is concluded that 48 hours is maximum tolerable for air transport missions.

Bergstrom, B. The effect of sleep loss and threat induced stress upon tracking. Scandinavian Journal of Psychology, 13, 54-60.

Bergstrom, Bengt, Gillberg, Mats, and Arnberg, Peter. (1973). Effects of Sleep Loss and Stress upon Radar Watching. Journal of Applied Psychology, 38(2), 158-162. (Abbreviated Synopsis in Appendix B).

Bergum, B.O. (1966). A taxonomic analysis of continuous performance. Perceptual and Motor Skills, 23, 47-54.

Task: Various - a theoretical paper.

Notes: A nice analysis of tasks based on their activation levels. Only remotely relevant.

Berkun, Mitchell M. (1962). Experimental Studies of Psychological Stress in Man. Alexandria, VA: George Washington Univ., Human Resources Research Office. (Abbreviated Synopsis in Appendix B).

Berkun, Mitchell M. (1964, February). Performance Decrement Under Psychological Stress. Presidio of Monterey, CA: Human Resources Research Office. Also in Human Factors, 6(1). (Abbreviated Synopsis in Appendix B).

Berkun, Mitchell M., Bialek, Hilton, M., Yagi, Kan, Berry, James L., Kern, Richard P. (1959, December). Human Psychophysiological Response to Stress: Successful Experimental Simulation of Real-Life Stresses. Alexandria, VA: Human Resources Research Office, George Washington Univ. (Abbreviated Synopsis in Appendix B).

Berkun, Mitchell, M., Walker, Jerald N., Meeland, Tor. (1958, November). Inferred Correlation Between Combat Performance and Some Field Laboratory Stresses. Alexandria, VA: Human Resources Research Office, George Washington Univ.

Task: Performance in combat (as judged by infantrymen peers in Korea).

Stressors: Combat, simulated combat & various other stressful experimental tasks.

Notes: Attempt to see whether certain written tests were predictive of performance both in actual combat & stressful simulation tasks. No success. Authors conclude stressful simulations not good enough. Maybe so, but selection of predictor variables could have been better.

Bink, B. (1962). The physical working capacity in relation to working time and age. Ergonomics, 5(1), 25-28.

Bonjer, F. Actual energy expenditure in relation to the physical working capacity. Ergonomics, 29-31.

Bonnet, M.H. (1980). Sleep, performance and mood after the energy-expenditure equivalent of 40 hours of sleep deprivation. Psychophysiology, 17, 56-63. (Abbreviated Synopsis in Appendix B).

Boyles, Wiley R. (1969). Measures of reaction to threat of physical harm as predictors of performance in military aviation training. Alexandria, VA: Human Resources Research Organization.

Task: Learning to fly Army aircraft.

Stressors: Risk of injury associated with participation in various physical activities.

Notes: Attempt to use biographical data to predict success in pilot training. Title is misleading.

Brixtson, Clyde A. (1975). Longitudinal Study of Environmental Variables and Aviation Performance Effectiveness. LaJolla, CA: Dunlap and Associates.

Task: Carrier landings of F4J aircraft during Vietnam conflict.

Stressors: Disrupted sleep, night operations, high workload, extended cruise (9 mos).

Notes: Sleep data collected over 1 7-day period. Irregular sleep associated with poorer performance.

Brouha, L. (1967). Role of climatic and environmental conditions in weight carrying. Industrial Medicine and Surgery, 257-266.

Brown, Bill R., Morgan, Ben B. Jr. (1973). Studies of performance assessment and enhancement. Louisville, KY: Univ. of Louisville. Performance Research Lab.

Brown, Frank L. and Jacobs, T.O. (1967). Critical Combat Performances. Knowledges, and Skills Required of the Infantry Rifle Platoon Leader: Human Maintenance Under Campaign Conditions. Alexandria, VA: Human Resources Research Organization.

Task: Soldier maintenance. This is a handbook for infantry platoon leaders.

Stressors: Combat exhaustion, others.

Notes: Addresses problems of sleep loss, physical exertion, stress, in terms of what to do.

- Brown, Frank L., and Jacobs, T.O. (1970). Developing the Critical Combat Performance Required of the Infantry Rifle Platoon Leader. Ft. Benning, GA: Human Resources Research Organization.
- Buck, Leslie. (1975). Sleep Loss Effects on Movement Time. Ergonomics, 18(4), 5-425. (Abbreviated Synopsis in Appendix B).
- Bugge, J.F., Opstad, P.K., and Magnus, P.M. (1979). Changes in the circadian rhythm of performance and mood in healthy young men exposed to prolonged heavy physical work, sleep deprivation, and caloric deficit. Aviation, Space, and Environmental Medicine, 50, 663-668. (Full Synopsis in Appendix A).
- Cameron, C. (1971). Fatigue problems in modern industry. Ergonomics, 14, 713-720.
- Cameron, C. (1973). A Theory of Fatigue. Ergonomics, 16(5), 633-648.
- Task: No specific tasks.
 Stressors: Long term work.
 Notes: This is strictly theoretical, but offers some important insights concerning the findings of research on fatigue.
- Cannon, Dennis, Drucker, Eugene, Kessler, Theodore. (1964). Summary of Literature Review on Extended Operations. Human Resources Research Office.
- Stressors: Sleep loss, temperature, vibration, confinement, noise & others.
 Notes: Study performed by Armor Research Unit, Ft. Knox. Authors conclude that literature to that time precludes supporting or denying that troops can remain effective for 48 hrs or longer.
- Capretta, P.J., Berry, James L., Kerle, Robert H., and LaMonaca, Hugh L. (1960). Validity and Reliability of Certain Indicators of Psychological Stress. (Research Memo). Alexandria, VA: Human Resources Research Office, Geo. Washington Univ.
- Task: Digit-symbol substitution, number checking, rifle disassembly & assembly, backwards digit span (believed stress sensitive).
 Stressors: Taking backwards digit span test at the midpoint of a rope bridge 50' above a rocky canyon.
 Notes: Test showed significant but very small degradation effects due to stressor. Other tests administered after stress showed no effects. Authors note S's did not perceive any threat to their survival.
- Caputo, Philip. (1977). A rumor of war. Ballantine books.
- Cash, John A. (1970). Flight at Ia Drang, from Seven Firefights in Vietnam. US Army Office of Military History.

- Chermol, Brian H. (1983, September). The quiet enemy: combat stress. Army, 33(9).
- Chiles, Walter D. (1955). Experimental Studies of Prolonged Wakefulness. (Tech Report 55-395). Wright Air Development Center. (Abbreviated Synopsis in Appendix B).
- Clark, Rodney A. (1955). Leadership in Rifle Squads on the Korean Front Line. George Washington University.
- Cleary, F.K. (1968). Critical Combat Performances, Knowledge, and Skills Required of the Infantry Rifle Platoon Leader, Emplacements, Shelters, Obstacles, and Field of Fire. Alexandria, VA: Human Resources Research Organization.
- Cleary, F.K., et al. (1968). Critical Combat Performances, Knowledge and Skills Required of the Infantry Rifle Platoon Leader, Offensive Operations. Alexandria, VA: Human Resources Research Organization.
- Cohen, S. Aftereffects of Stress on Human Performance and Social Behavior: A Review of Research and Theory. Psychological Bulletin, 88, 82-108.
- Task: Various - this is a review article.
- Stressors: Noise, electric shock, bureaucratic stress, arbitrary discrimination, etc.
- Notes: Makes the interesting case that continued exposure to a stressor may produce effects that appear only after the stimulation has been terminated - the adaptive-cost hypothesis.
- Collins, W.E. (1977). Some effects of sleep deprivation on tracking performance in static and dynamic environments. Journal of Applied Psychology, 62, 567-573.
- Colquhoun, W.P. (1985). Hours of work at sea; watchkeeping schedules, circadian rhythms and efficiency. Ergonomics, 28(4), 637-653.
- Task: Sonar signal detection (auditory).
- Stressors: Circadian influence; stable vs. rotating watch.
- Colquhoun, W.P., Hamilton, P., and Edwards, R.S. (1974). Signal Detection Efficiency in the Morning Watch. Effects of Prior Sleep, Diurnal Rhythm and Fatigue. (Report No. DES-10/74; DRIC-BR-51850). London, England: Royal Navy Personnel Research Committee.
- Task: Sonar signal detection.
- Stressors: Lack of sleep just prior to the morning watch. 4 on - 4 off - 4 on schedule.
- Notes: 30% to 50% reductions in detection rate.
- Colquhoun, W.P., Watson, K.J., and Gordon, D.S. (1987). A shipboard study of a four-crew rotating watchkeeping system. Ergonomics, 30(9), 1341-1352.

Covey, R.W. (1969). Dropouts in Combat: A Stochastic Model. (Masters Thesis). Monterey, CA: Naval Postgraduate School.

Task: Develop a model that takes into account not just attrition in combat, but other factors that result in non-effective performance.

Stressors: Combat, fatigue.

Notes: Interesting observations on fatigue, pp. 20-22. Definitions p. 20.

Cox, D., Hallam, R., O'Connor, K., and Rachman, S. (1983). An experimental analysis of fearlessness and courage. British Journal of Psychology, 74(1), 107-117.

Task: Adjustment of lever in response to tone discrimination.

Stressors: Electric shock in case of incorrect choice.

Notes: Subjects were bomb disposal personnel and others, for control.

Dhalke, A.E., and Burkett, Ron. (1984). Psychological reactions to non-nuclear weapons: problems and potentials of the experimental approach. In Proceedings, First Symposium on the Psychological Effects of Non-Nuclear Weapons. Univ. of Oklahoma.

Task: N/A - a plea for experiments incorporating both laboratory and field characteristics

Stressors: Fear caused by enemy fire.

D'Amico, Anita D., Kaufman, Edmund, and Saxe, Christine. (1986). A simulation study of the effects of sleep deprivation, time of watch, and length of time on watch on watchstanding effectiveness. Kings Point, NY: Nat'l Maritime Research Center.

Task: Detection of other ships, detection of instrument failure, frequency/duration of radar observations.

Stressors: Kept awake all night prior to a 4-hour daytime watch.

Notes: Poorly conceived watch sequence - no night watches - no repetitions.

Daniels, W.L., Vogel, J.A., and Jones, B.H. (1984). Comparison of Aerobic Power and Dynamic Lift Capacity with Performance during a 5-day Sustained Combat Scenario. Natick, MA: Army Research Inst of Environmental Medicine.

Task: Series of 24 hr missions calling for all kinds of combat-related tasks.

Stressors: 5 days (120 hrs) of operations with 4 hrs sleep every 24.

Notes: No data on task performance other than a single (rating) score ranging on a scale from 1-10.

Davey, C.P. (1973). Physical exertion and mental performance. Ergonomics, 16, 595-599.

Task: Perception of specified pattern in aurally presented sequence of digits.

Stressors: Amount of physical work performed (bicycle ergometer).

Notes: Neat little study showing an inverted U relationship between amount of physical exertion & attention-demanding performance.

Davis, D. Russell. (1979). Pilot Error: Some Laboratory Experiments. In Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1948 report.)

Davis, D.R. (1948). The disorder of skill responsible for accidents. Quarterly Journal of Experimental Psychology, 1, 136-142.

Task: Not described. Skilled Response test.

Stressors: Work in coal mines.

Notes: Not relevant to our interests.

Davis, D.R. (1946). The disorganization of behaviour in fatigue. Journal of Neurology and Psychiatry, 2, 23-29.

Davis, H. Faulkner, T., and Miller, C. (1969). Work physiology. Human Factors, 11(2), 157-166.

Davis, S.E. & Taylor, J.G. (1954, September 30). Stress in Infantry Combat. (Tech Memo ORO-T-295). Chevy Chase, MD: Operations Research Office, John Hopkins University.

Task: Infantry attack on Triangle Hill (Korea).

Stressors: Enemy action, high casualty rate, up to 5 days combat.

Notes: Lots of physiological data but very poor psychological test data. A lesson in how not to go about it.

Dearnley, E.J. and Warr, F.B. (Eds.). (1979). Aircrew stress in wartime operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press.

Task: Various aircraft control maneuvers.

Stressors: Length of time flying: up to 10 hours in aircraft; about 2 hours in simulator.

Notes: Data in Chapters 5, 8 and 9 are probably very specific to flying (very old aircraft). Other chapters in book are not relevant.

Dedmon, James F., and Mielec, Roger. (1984). Customer Test (Phase 1B) of the Surrogate Research Vehicle. (Limited distribution). Fort Knox, KY: U.S. Armor and Engineer Board.

Notes: SRV crews performed during three 72-hour continuous exercises under simulated NBC threat.

Deese, J., and Lazarus, R.S. (1952). The effects of psychological stress upon perceptual motor performance. (Research Bulletin 52-19), Lackland Air Force Base: Perceptual and Motor Skills Research Lab.

Defense Logistics Agency, Human Variables in Combat. Defense Technical Information Center, Technical Report Summaries.

Task: Various (combat).

Stressors: Continuous operations, chemical warfare environment, physical work, dark environment, noise, heat, confinement, air-to-ground fire.

Defense Logistics Agency. Combat Fatigue. Defense Technical Information Center, Technical Report Summaries, Search control no. 055241.

Task: Various (combat).

Stressors: Continuous operations, sleep deprivation.

Notes: Several articles of interest ordered.

Defense Logistics Agency. Combat Fatigue. DTIC, Technical Report Summaries, Search control no. 055245.

Task: Various (combat).

Stressors: Stress, fatigue.

Notes: Two articles of interest ordered.

Defense Logistics Agency. Combat Stress. Defense Technical Information Center, Technical Report Summaries.

Task: Various (combat).

Stressors: Reduced sleep, continuous operations, suppression, respiratory/thermal (NBC), confinement in armored vehicles.

Notes: Many articles of interest ordered.

Dept. of the Army. (1970). Reduction of Reaction Time to Engage Enemy Targets. Dept. of Army, Army Concept Team in Vietnam.

Dept. of the Army. (1967). Operations Report - Lessons Learned - Observations of a Platoon Leader. Washington, DC: DTIC.

Dept. of the Army. (1977). Army Training and Evaluation Program for Armored Cavalry Squadron. ARTEP 17-55.

Dept. of the Army. (1972, November). Tank Gunnery - Field Manual. Dept. of Army, HQ.

Dept. of the Army. (1969, November). Fifteenth Annual Army Human Factors Research and Development Conference. Dept. of Army.

Dept. of the Army. (1969, March). A Study of the Factors Which Account for the Differences Between Effective and Ineffective Rifle Squads. Alexandria, VA: Human Resources Research Organization.

Task: No performance measures; all attitudinal.
Stressors: N/A
Notes: Rather misleading title

Dept. of the Army. (1983, December). Soldier Performance in Continuous Operations. Dept. of the Army, Field Manual 22-9.

Task: Cope with demand for continuous operations.
Stressors: Sleep loss; fatigue; limited visibility; disruption of wake/sleep cycles.
Notes: Projected performance degradation curves for armor, mechanized infantry, fire support teams, artillery given. Expected effects on psychological processes. Believed to be based on work of Siegel, et al. (See synopsis, this document).

DeVries-Griever, A.H.G., and Meijman, T. F. (1987). The impact of abnormal hours of work on various modes of information processing: A process model on human costs of performance. Ergonomics, 30(9), 1287-1299. (Abbreviated Synopsis in Appendix B).

Dewulf, G. A. (1987). Continuous Operations Study (CONUPS) Final Report. Ft. Leavenworth, KS: US Army Combined Arms Combat Development Activity, Force Design Directorate. (Full synopsis in Appendix A).

Dinges, D.F., Orne, E.C., Evans, F.J., and Orne, N.T. (1981). Performance after Naps in Sleep-Conducive and Alerting Environments. In The Twenty-Four Hour Workday: Proceedings of a Symposium on Variations in Work-Sleep Schedules. Cincinnati, OH: U.S. Dept. of Health & Human Services.

Task: RT, answering the phone, descending subtraction.
Stressors: Sudden awakening from nap of 60 min.
Notes: Subjects were not sleep deprived. Immediate performance loss upon nap interruption but no study of duration of effect.

Dinges, David F., Orne, Martin T., and Orne, Emily Carota. (1985). Assessing performance upon abrupt awakening from naps during quasi-continuous operations. Psychonomic Society. In Behavior Research Methods, Instruments, & Computers. 17(1). (Abbreviated Synopsis in Appendix B).

Dinges, David F., Orne, Martin T., Orne, Emily Carota, and Evans, Frederick J. (1980). Voluntary Self-Control of Sleep to Facilitate Quasi-Continuous Performance. Fort Detrick, Frederick, MD: U.S. Army Medical Research and Development Command.

Task: Descending subtraction; random number generation, telephone ring RT.
Stressors: None.
Notes: Includes excellent review of effects of napping (short sleep) in continuous military operations.

Dollard, John. (1969, August). Fear in Battle. (Technical Library, USA CDCEC. 355.1294 Do.). Ft. Ord, CA.

Stressors: Combat.

Notes: Primary data are results of opinion survey. Concerned with fear as a stressor.

Donnell, J.M. (1969). Performance decrement as a function of total sleep loss and task duration. Perceptual and Motor Skills, 29, 711-714.

Task: Wilkinson addition test.

Stressors: 64 hrs of sleep loss.

Notes: Clearly demonstrates need for tests of more than a few minutes duration when trying to determine effects of sleep loss. 50 min. of testing were required to detect significant decreases in accuracy on 1st deprivation day; only 10 minutes required on 2nd deprivation day.

Drew, G.C. (1979). An Experimental Study of Mental Fatigue. Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press.

Notes: See Dearnaley and Warr, 1979.

Drucker, E.H., Cannon, L.D., and Ware, J.R. (1969). The Effects of Sleep Deprivation on Performance Over a 48-hour Period. (Technical Report No. 69-8). Human Resources Research Office. (Full synopsis in Appendix A).

Task: Target detection, identification by AFV commander, using different night vision display systems.

Stressors: Sleep deprivation - 5 days, limited to 3 80-min cat naps per 24 hrs.

Notes: Important study. Detection performance impaired (see classified details).

Duncan, Chester E., Sanders, Michael G., Kimball, Kent A. (1980). Evaluation of Army Aviator Human Factors (Fatigue) in a High Threat Environment. Fort Rucker, AL: Army Aeromedical Research Lab.

Task: Piloting Army aircraft.

Stressors: Various flight conditions, particularly night time and nap-of-earth flying.

Notes: Questionnaire survey of Army aviators. Generated different fatigue ratings for different flight profiles. Possibly useful list of factors influencing pilot fatigue shown on pg 34 & 54.

Dupuy, T.N. (1979). The Effects of Combat Losses and Fatigue on Combat Performance. Historical Evaluation and Research Organization. (US Government Limited document). Fort Monroe, VA: Training and Doctrine Command. (Abbreviated Synopsis in Appendix B).

Easterbrook, J.A. (1959). The effect of emotion on cue utilization and the organization of behaviour. Psychological Review, 66, 183-207.

Edwards, A.S. (1941). Effects of the loss of 100 hours of sleep. Amer. J. Psychol., 54, 80-91. (Abbreviated Synopsis in Appendix B).

Egbert, Robert L., Maeland, Tor et al. (1958). Fighter 1: A study of effective and ineffective combat performers. Human Resources Organization.

Task: Identify psychological attributes that differentiate between men in Korean war classed as "fighters" & "non-fighters."

Stressors: Combat (Korea).

Notes: Fighters & non-fighters identified by peer nomination procedure. Specific examples of good & poor performance were required. 40 psychological tests administered that showed a number of differences between good & poor performers.

Egbert, Robert L., Maeland, Tor., Cline, Victor B., Forgy, Edward W., Spickler, Martin W. and Brown, Charles. (1957). Fighter 1: An Analysis of Combat Fighters and Non-Fighters. (Technical Report 44). Presidio of Monterey, CA: U.S. Army Leadership Human Research Unit.

Elkin, A.J., and Murray, D.J. (1974). The effects of sleep loss on short-term recognition memory. Canadian Journal of Psychology, 28, 192-198.

Ellingstad, V.S., and Heimstra, N.W. (1970). Performance changes during the sustained operation of a complex psychomotor task. Ergonomics, 13(6) 693-705. (Abbreviated Synopsis in Appendix B).

Emanski, J.J. (1977). Continuous land combat. (Tech Report No. 4940). Menlo, Park, CA: SRI International.

Task: All aspects of continuous land combat.

Stressors: Day and night, all weather operations. Chemical, biological, radiological warfare.

Notes: Useful as description of requirements for continuous operations. Section 10 emphasizes fatigue, requirement to operate at night, to operate buttoned up, and to experience CBR and nuclear horror as the major human factor problems.

Englund, C.E., Naitoh, P., Ryman, D.H., Hodgdon, J.A. (1983). Moderate Physical Work Effects on Performance and Mood During Sustained Operations (SUSOPS). (Report No. 83-6). San Diego, CA: Naval Health Research Center. (Full Synopsis in Appendix A).

Englund, Carl E., Ryman, David H., Naitoh, Paul and Hodgdon, James A. (1985). Cognitive performance during successive sustained physical work episodes. Psychonomic Society, Inc. In Behavior Research Methods, Instruments, & Computers, 17(1). (Full Synopsis in Appendix A).

Ernsting, J. (Ed.) (1983). Sustained intensive air operations: physiological and performance aspects. Proceedings of the NATO Advisory Group for Aerospace R&D (AGARD). Aerospace Medical Panel Specialists' Meeting at Paris, France. Loughton, Essex, United Kingdom: Specialised Printing Services, Ltd.

Task: Various - collection of symposium papers.

Stressors: Sustained operations.

Notes: See papers by: Kleinhanz; Ursin; Storm; Kimball; Sanders; Nicholson; Angus, Wegmann; and O'Donnel.

Evans, F.J., and Orne, M.T. (1975). Recovery from fatigue. (Final report on Contract No. DADA 17-71-C-1120). Washington, D.C: U.S. Army Medical Research and Development Command.

Task: Successive subtraction; random number generation.

Stressors: 36 hrs of continuous work. 4 hrs of recovery sleep.

Notes: Study of different kinds of nappers (who may differentially benefit from naps); also one study of continuous (36 hr) work. Poor selection of performance tests and administrative procedures.

Evans, W.J., Winsmann, F.R., Pandolf, K.B., and Goldman, R.F. (1980). Self-paced hard work comparing men and women. Ergonomics, 23(7), 613-621. (Full Synopsis in Appendix A).

Fenz, W.D. and Craig, J.G. (1972). Autonomic arousal and performance during sixty hours of sleep deprivation. Perceptual and Motor Skills, 34, 543-553.

Task: Speech perception, rhythm test, tapping test; trail making test; sensory perception test.

Stressors: 60 hrs without sleep.

Notes: Short laboratory tests administered only during morning and evening. Predictably, only limited effects on performance during latter stages of the 60 hour period.

Fenz, W.E. and Jones, B. (1972). The effect of uncertainty on mastery of stress: A case study. Psychophysiology, 9, 615-619.

Fine, E., and Kobrick, J. (1987). Effect of heat and chemical protective clothing on cognitive performance. Aviation, Space, and Environmental Medicine, 58, 149-154. (Abbreviated Synopsis in Appendix B).

Fine, Bernard J., and Kobrick, John L. (Date unknown; post 1983). Sustained Human Performance in the Heat: Summary of an On-going Systematic Research Program. Natick, MA: U.S. Army Research Institute of Environmental Medicine.

Florica, V., Higgins, E., Iampietro, M., and Davis, A. (1968). Physiological responses of men during sleep deprivation. J. of Appl. Physiol., 24(2), 167-176.

Floyd, W.F., and Welford, A.T. (Eds.) (1953). Symposium on Fatigue. London: H.K. Lewis & Co.

- Forbes, J.L. (1986). Training lessons learned from peak performance episodes. U.S. Army Research Inst. for the Behavioral and Social Sciences.
- Folkard, Simon, and Condon, Ruth. (1987). Night shift paralysis in air traffic control officers. Ergonomics, 30(9), 1353-1363.
- Francesconi, R.P., Stokes, J.W., Banderet, L.E., and Kowal, D.M. (1978). Sustained operations and sleep deprivation: Effects on indices of stress. Aviation, Space, and Environmental Medicine, 49, 1271-1274. (Abbreviated Synopsis in Appendix B).
- Frazier, T.W., Benignus, V.A., Every, M.G., and Parker, J.F. Jr. (1971). Effects of 72-Hour Partial Sleep Deprivation on Human Behavioral and Physiological Response Measures. Falls Church, VA: BioTechnology Inc. (Abbreviated Synopsis in Appendix B).
- Friedmann, J., Globus, G., Huntley, A., Mullaney, D., Naitoh, P., & Johnson, L.C. (1977). Performance and mood during and after gradual sleep reduction. Psychophysiology, 14, 243-250.
- Task: Word memory, digit span, vigilance (auditory), addition, rapid alternation task (button pushing).
- Stressors: Progressive reduction (over 6-8 mos) of sleep allowed down to 4.5 to 5.5 hrs/nite.
- Notes: Authors claim no measurable performance effects. Subjects lived at home. Testing occurred periodically at Naval Health Research Center and took place on a single day. Subjective fatigue definitely occurred. No discussion of possible uncontrolled napping.
- Froberg, J.E., Karlsson, C.G., Levi, L., and Lidberg, L. (1975). Circadian rhythms of catecholamine excretion, shooting range performance and self-ratings of fatigue during sleep deprivation. Biol. Psychol., 2, 175-188.
- Task: Firing electronic rifle at small moving targets.
- Stressors: 72 hrs without sleep, 95dB-C recorded battle noise, confinement to chair on range.
- Notes: Progressive decreases in number of shots and number of hits over the 72 hr period. Circadian effects also shown that followed the curves for adrenaline secretion.
- Frost, Dean E., Fiedler, Fred E., Anderson, Jeff W. (1983). The role of personal risk-taking in effective leadership. Duquesne U, School of Business & Administration. Human Relations, 36(2), 185-202.
- Furman, J.S., and Wampler, R.L. (1982). Methodology for Evaluation of Unit Tactical Proficiency at the National Training Center. (Master's Thesis). Monterey, CA: Naval Postgraduate School.
- Task: Infantry and armor battle operations.
- Stressors: Threat of defeat by OPFOR.

Notes: Contains useful information on how NTC operates; discusses need for better methods of evaluating tactical proficiency. Appendix lists NTC training missions, MOE's, MOP's. Measures used at NTC described.

Futterer, J.W. (1983). Preliminary Results of a Psychologist's Observation and Participation with a Combat Unit during Continuous Operations. El Paso, TX: William Beaumont Army Medical Center. (Abbreviated Synopsis in Appendix B).

Gal, Reuven. (1986). Yesterday's Conventional Warfare - Tomorrow's Nuclear Warfare? The Israeli Institute for Military Studies.

Gander, Philippa H., and Graeber, R. Curtis. (1987). Sleep in pilots flying short-haul commercial schedules. Ergonomics, 30(9), 1365-1377.

Garg, A., and Saxena, U. (1979). Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate. Am. Ind. Hyg. Assoc. J., 40(10), 894-903. (Abbreviated Synopsis in Appendix B).

Gartner, Walter B., and Murphy, Miles R. (1976). Pilot Workload and Fatigue: A Critical Survey of Concepts and Assessment Techniques. Moffett Field, CA: NASA, Ames Research Center.

Task: N/A. Review article (158 refs) on problems of defining fatigue and measuring it.

Stressors: Fatigue, workload.

Notes: May be useful if we get into problems of definition.

Geier, R.P. (1979). Sleep loss: A debt that must be paid. Armor, 37-38.

Task: Effective command of armor.

Stressors: Sleep deficit.

Notes: Neat popular article expressing the views of an Army armor officer.

George, Clay E., and Dudek, R.A. (1974). Performance, recovery and man-machine effectiveness: Final report on a basic research program under project THEMIS. (USAHEL Report No. TM-9-74). Aberdeen Proving Ground, MD: US Army Human Engineering Lab.

Task: Various - a review article.

Stressors: Long-term performance, vibration, heat.

Notes: Summary of 5 years of research purportedly aimed at continuous operations. Nothing over 24 hrs in duration, and that limited to physiological studies.

Gertman, David I., Haney, Lon N., Jenkins, James P., and Blackman, Harold S. (1985). Operational Decisionmaking and Action Selection Under Psychological Stress in Nuclear Power Plants. U.S. Nuclear Regulatory Commission.

Giambra, L.M. and Naylor, J.C. (1966). Combat Incidents Illustrating Psychological Reaction to Weapons - A Factor Analysis (U). (Final Report (July 1, 1965 - March 31, 1966). ATL-TR-66-43). Behavioral Sciences Laboratory, Ohio State University.

Task: Non-specific, combat.

Stressors: Fire from all classes of weapons used in Vietnam, Korea.

Gibbs, C.B., Leonardo, R., & Rowlands, G.F. (1968). The effects of psychological stress upon decision processes and the speed and precision of tracking movements. 1: Study of the effects of sleep deprivation and disturbance. (NRC Report No. NRC-10397, NL-2). Ottawa, Ontario, Canada: National Research Council of Canada.

Task: (1) Target position tracking where direction of target movement varied in probability (the stressalyzer); and (2) mirror tracking.

Stressors: 48 hrs sleep deprivation, also disrupted sleep.

Notes: Sharp deterioration in tracking response after 20 hrs without sleep; further deterioration at the 36 hr stage. In some subjects sleep disturbance at 0100 and 0500 produced more loss in performance than complete sleep deprivation at same stage in testing.

Givoni, B., and Goldman, R. (1973a). Predicting heart rate response to work, environment, and clothing. Journal of Applied Physiology, 34(2), 201-204. (Abbreviated Synopsis in Appendix B).

Givoni, B., and Goldman, R. (1973b). Predicting effects of heat acclimatization on heart rate and rectal temperature. Journal of Applied Physiology, 35(6), 875-879.

Glenville, M., Broughton, R., Wing, A.M., and Wilkinson, R.T. (1978). Effects of sleep deprivation on short duration performance measures compared to the Wilkinson Auditory Vigilance Task. Sleep, 1, 169-176. (Abbreviated Synopsis in Appendix B).

Glenville, Marilyn, Wilkinson, Robert T. (1979). Portable devices for measuring performance in the field: The effects of sleep deprivation and night shift on the performance of computer operators. Ergonomics, 22(8), 927-933.

Task: Simple RT, four choice serial RT.

Stressors: Night shift work (only minor sleep deprivation).

Notes: Performance tests only 10 min long. Pronounced difference between day shift and night shift performance but only after 4+ weeks of testing.

Goldman, R.F. (1965). Energy expenditures of soldiers performing combat type activities. Ergonomics, 8, 321.

Gordon, D.A. (1957). A Survey of Human Factors in Military Night Operations. Washington, DC: Human Resources Research Office.

Gorham, W.A., and Orr, D.B. (1958). Research on behavior impairment due to stress: Experiments in impairment reduction. (Final Report, Project No. 7707). Washington, DC: American Institutes for Research.

Task: SAM complex coordination test, SAM motor judgment test, SAM direction control test, vigilance, mathematics.

Stressors: Electric shock (painful), intense electric spark activated few inches from subject's face.

Notes: Only study encountered with tests of specific hypotheses about how to reduce effects of stress on performance. However, test periods were short (30 min). Evidence of genuine fear response and behavior disorganization among the subjects.

Grandjean, E., Baschera, P., Martin, E., and Weber, A. (1977). The effects of various conditions on subjective states and critical flicker frequency. In Mackie, Robert R. (Ed.) Vigilance: Theory, operational performance and physiological correlates. New York and London: Plenum Press.

Grandjean, E.P., Wotzka, G., Schaad, R., and Gilgen, A. (1971). Fatigue and Stress in Air Traffic Controllers. Ergonomics, 14(1), 159-165.

Task: Air traffic control performance (not measured), CFF, tapping test, grid tapping test.

Stressors: The job itself - performed over 10 hr period.

Notes: Notable performance decrements on experimental tests after 6 hrs on job.

Grether, Walter F. (1970). Effects on human performance of combined environmental stresses. (No. 70-68, 15 p.) Wright-Patterson Air Force Base, O: Air Force Systems Command, Aerospace Med Res. Lab.

Gruber, A., et al. (1965). Development of a Methodology for Measuring Infantry Performance in Rifle Firing and Reloading. Dunlap & Associates, Inc.

Gruber, E.K.E. (1966). Adaptation to extreme environments: Prediction of performance. (Report No. 66-17). San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

Gupta, J., Swamy, Y., Dimri, G., and Pichan, G. (1981). Physiological responses during work in hot humid environments. Ind. Journ. Physiol. Pharmac., 25(4), 339-347. (Abbreviated Synopsis in Appendix B).

Hagberg, J., Mullin, J., and Nagle, F. (1980). Effect of work intensity and duration on recovery O₂. J. Appl. Physiol., 48(3), 540-544.

Haggard, D.F. (1970). HumRRO studies in continuous operations. (HumRRO professional paper 7-70). Human Resources Research Organization. (Full Synopsis in Appendix A).

Haggard, Ernest A. (1949). Psychological Causes and Results of Stress. Chapter 21 in a Survey Report on Human Factors in Undersea Warfare.

Hamelin, Patrick. (1987). Lorry driver's time habits in work and their involvement in traffic accidents. Ergonomics, 30(9), 1323-1333.

Hammerton, M., and Tickner, A.H. (1968). An investigation into the effects of stress upon skilled performance. Ergonomics, 12(6), 851-855.

Task: Learning to track a spot on CRT into desired location quickly.

Stressors: Imminence of parachute jump.

Notes: Performance was affected by anxiety associated with parachute jump; however, anxiety effects can be reduced through training.

Hancock, P.A. (1986, January). The Effect of Skill on Performance Under an Environmental Stressor. Aviation, Space, and Environmental Medicine.

Task: Various including telegraphic reception, visual signal detection.

Stressors: Heat.

Notes: Not relevant unless concerned with heat stress; good references on this stressor.

Harmon, L.R., Drucker, A.J. (1953). Reasons Given by Squad and Platoon Leaders for Judging Soldiers as Failures in Combat. TAGO Personnel Research Branch, Research Memorandum 53-52.

Task: None given.

Stressors: None given.

Notes: Title misleading. No reasons cited, just a sorting scheme reflecting number of nominations received.

Harris, D.A., Pegram, G.V., and Hartman, B.O. (1971). Performance and fatigue in experimental double-crew transport missions. Aerospace Medicine, 42, 980-986.

Task: Various crew performance tasks - rated subjectively.

Stressors: 4/4 vs. 16/16 work-rest. 43 hrs (av.) flying time.

Notes: No objective performance measures. No effects on rated performance. No differential effect of work-rest pattern.

Harris, David W. (1985). A Degradation Analysis Methodology for Maintenance Tasks. (Master's Thesis), Georgia Institute of Technology.

Task: Maintenance tasks on M-60 machine gun.

Stressors: Wearing chemical protective clothing.

Notes: Primary data from model predictions. Of interest if concerned with protective clothing problem.

Harris, F. Gentry, Mayer, Joseph, and Becker, Herman A. (1955). Experiences in the Study of Combat in the Korean Theater. Washington, DC: Walter Reed Army Institute of Research

Harris, W., Mackie, R.R. and Wilson, C.L. (1956). Research on the Development of Performance Criteria. Technical Report IV: Performance under stress: A review and critique of recent studies. (Technical Report 204-6). Goleta, CA: Human Factors Research.

Notes: Describes several types of research paradigms used in research on stress and probable reasons for diverse outcomes.

Harris, W. and O'Harion, J. F. (1972). A study of recovery functions in man. (Technical Report 1723-F). US Army Human engineering Laboratory Technical Memo 10-72. Goleta, CA: Human Factors Research, Inc. (Abbreviated Synopsis in Appendix B).

Hartman, B. (1965). Fatigue effects in 24-hour simulated transport light. Change in pilot proficiency. (Tech. Report, SAM-TR-65-17). Brooks AFB, TX: USAF School of Aerospace Med.

Hartman, B.O. (1971). Field study of transport aircrew workload and rest. Aerospace Medicine, 42, 817-821.

Task: Flying C-141's.

Stressors: 9 days of operations with 44.5 hrs of flying.

Notes: Crewman had plenty of opportunity to sleep (av. = 7.3 hrs).

Hartman, B.O., and Cantrell, G.K. (1967). MOL: Crew Performance on Demanding Work-Rest Schedules Compounded by Sleep Deprivation. (Technical Report 67-99). Brooks AFB, TX: School of Aerospace Medicine.

Task: Complex coordination; multi-dimensional pursuit; vigilance; ST memory; arithmetic; tracking; multiple reaction time.

Stressors: Continuous work for 3 days without sleep, following 7 days of work on different work/rest schedules.

Notes: Very comprehensive study. Data on both performance decrement and recovery.

Hartman, B.O., Ensel, R.A., & Storm, W.F. (1980). A review of USAFSAM studies employing multiple-task performance devices. (SAM report No. TR 80-16). Brooks Air Force Base, TX: USAF School of Aerospace Medicine.

Hartman, B.O., Storm, W.F., Vanderveen, J.E., Vanderveen, E., Hale, H.B., & Bollinger, R.R. (1974). Operational aspects of variations in alertness. (AGARDograph No. 89). London: Technical Editing and Reproduction Ltd.

Hartman, B.O., Langdon, D.E., and McKenzie, R.E. (1965). A third study on performance upon sudden awakening. (Report No. SAM-TR-65-63). Brooks Air Force Base, TX: USAF School of Aerospace Medicine.

Task: Multi-dimensional pursuit test (aircraft rudder, stick, and throttle adjustments).

Stressors: Sudden awakening from sleep; immediate task performance after no more than 2 min. delay.

Notes: Task took 10 minutes. No evidence of recovery to pre-sleep levels of performance during that time.

Hashimoto, K., Kogi, K., and Grandjean, E. (Eds.) (1971). Methodology in Human Fatigue Assessment. London. Taylor and Francis.

Haslam, Diana R. (1981). The Military Performance of Soldiers in Continuous Operations: Exercises 'Early Call' I and II. In: The Twenty Four Hour Workday: Proceedings of a Symposium on Variations in Work-Sleep Schedules. Cincinnati, Ohio: U.S. Dept. of Health & Human Services. (Full Synopsis in Appendix A).

Haslam, D.R. (1982). Sleep loss, recovery sleep, and military performance. Ergonomics, 25(2), 163-178. (Full Synopsis in Appendix A).

Haslam, D.R. (1984). The military performance of soldiers in sustained operations. Aviation Space and Environmental Medicine, 55(3), 216-221. (Abbreviated Synopsis in Appendix B).

Haslam, Diana R. (1985a). Sleep deprivation and naps. Psychonomic Society, Inc. Behavior Research Methods, Instruments & Computers, 17(1). (Abbreviated Synopsis in Appendix B).

Haslam, Diana R. (1985b). Sustained operations and military performance. Psychonomic Society, Inc. In Behavior Research Methods, Instruments & Computers, 17(1). (Full synopsis in Appendix A).

Haslem, W.J. (1986). Twelve Testing Mistakes. Army Research, Development and Acquisition Magazine, 27(4).

Hastings, M., Jenkins, S. (1983). Goose Green, from The Battle for the Falklands. W. W. Norton and Co.

Havron, M., Lybrand, William A., and Cohen, Edwin. (1954). The Assessment and Prediction of Rifle Squad Effectiveness. (PRB TR No. 31.) Washington, DC: Psychological Research Associates.

Hayes, Theodore R., Chevalier, John R., and Porter, Craig D. (1985). Chemical Warfare Individual Protective Equipment. (SECRET). DTIC.

Task: F-16 sortie generation.

Stressors: Wearing individual protective equipment (IPE), heat, fatigue.

Notes: Effects of heat and fatigue were modelled and estimates of performance degradation made. Much subjective input. Values and sources not explicit.

Headley, D.B., Brecht-Clark, J. & Wittenberg, J.A. (1988) The Effects of the Chemical Defense Ensemble and Extended Operations on Performance and Endurance of Combat Vehicle Crews. (ARI Technical Report No. 811) Alexandria, VA: Army Research Institute. (DTIC No. ADB131688).

Note: Contains data on various studies of crew endurance wearing MOPP gear.

Hegge, Frederick W. (1982). The Future Battlefield: Human Dimensions and Implications for Doctrine and Research. Washington, DC: Walter Reed Army Inst. of Research. (Abbreviated synopsis in Appendix B).

Helmstra, N.W. (1970). The Effects of Stress Fatigue on Performance in a Simulated Driving Situation. Ergonomics, 13(2), 209-218.

Task: Tracking (simulated driving), speed maintenance, reaction time, vigilance.

Stressors: Electric shock, 6 hrs continuous operation.

Notes: Of possible interest because punishment by shock in response to performance errors led to greater deterioration of performance.

Herbert, Marvin J., Jaynes, William E. (1963). Performance decrement in vehicle driving. Ft. Knox, KY: Army Medical Research Lab.

Herr, Michael. (1980). Dispatches. New York: Avon Publishers.

Heslegrave, R.J., & Angus, R.G. (1985). The effects of task duration and work-session location on performance degradation induced by sleep loss and sustained cognitive work. Psychonomic Society Inc: Behavior Research Methods, Instruments & Computers, 17, 592-603. (Abbreviated synopsis in Appendix B).

Heslegrave, R.J., and Angus, R.G. (1983). Sleep Loss and Sustained Performance. In: Proceedings of the 24th Defense Research Group Seminar on The Human as a Limiting Element in Military Systems. (Volume I). Toronto, Canada.

Task: Message processing, serial RT, encode/decode, logical reasoning, subtraction, ST memory, paired associates learning, map plotting.

Stressors: 54 hrs without sleep.

Notes: This is essentially the same study as Angus & Heslegrave (#304). It is a key study, performed under simulated command post operations during sustained battle.

Hicks, S.A. (1960). The effects of eight hours confinement in mobile armored personnel carriers on selected combat relevant skills: Study II. Tech Memo 17-60, USAHEL.

Task: Rail walking - equilibrium, obstructed run test - stamina and coordination, rifle firing, grenade throwing.

Stressors: 8 hrs confinement in APC.

Notes: Subjects experienced significant loss in equilibrium & coordination. Effects on rifle firing and grenade throwing uncertain.

Hicks, S.A. (1961a). The effects of twelve hours confinement in static armored personnel carriers on selected combat relevant skills: Study III. Tech Memo 1-61, USAHEL.

Hicks, S.A. (1961b). The effects of twelve hours confinement in mobile armored personnel carriers on selected combat relevant skills: Study IV. Tech Memo 2-61, USAHEL.

Hicks, S.A. (1961c). The effects of twenty-four hours confinement in mobile armored personnel carriers on selected combat relevant skills: Study V. Tech Memo 23-61, USAHEL.

Hicks, Samuel A. (1962). The effects of twenty-four hours confinement in mobile armored personnel carriers on selected combat relevant skills: a follow up. Aberdeen Proving Ground, MD: U.S. Army.

Hicks, S.A. (1964). The Effects of Confinement on the Performance of Combat Relevant Skill - Summary Report. (Technical Memorandum 16-64). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratories.

Task: Obstructed run course, grenade throw course, rail-walking course, rifle-fire course.

Stressors: Confinement up to 24 hrs in Armored Personnel Carrier; heat, vibration, noise, blast, cramping, air pollution, sleep deprivation.

Notes: Concludes that performance degradation in motor coordination, equilibrium & marksmanship seen in previous studies (see Hicks, 1962, (#367)) are relatively transient; also, decrements will become smaller with repeated confinements.

Hill, A. Bradford, and Williams, G.O. (1979). An Investigation of Landing Accidents in Relation to Fatigue. In Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press.

Notes: See Dearnaley and Warr, 1979.

Hockey, Robert (Ed.) (1983). Stress and Fatigue in Human Performance. John Wiley & Sons.

Tasks: Various. A review of research with little specific help for present objectives.

Hockey, G.R.J. (1970a). Changes in attention allocation in a multicomponent task under loss of sleep. British Journal of Psychology, 61, 473-480. (Abbreviated Synopsis in Appendix B).

Hockey, G.R.J. (1970b). Effect of loud noise on attentional selectivity. Quarterly Journal of Experimental Psychology, 22, 28-36.

Task: Target tracking (central visual field); visual monitoring of peripheral light flashes.

Stressors: Broad band noise (100 dB).

Notes: Noise actually improved tracking performance while simultaneously reducing rate of detecting peripheral signals. Author ascribes results to increased selectivity of attention with higher levels of arousal.

Hockey, G.R.J. (1973). Effects of noise and sleep loss on observation of 3 sources of signals with unequal probabilities. London, England: Royal Naval Personnel Research Committee.

Task: Detect red flashing signal while monitoring 3 sources of signals.

Stressors: Noise (100dBA), sleep loss (26 hrs).

Notes: Noise has beneficial effect in stimulating concentration on most probable signal sources, but increases number of misses as time at the task increases.

Hodge, D.C., Editor. (1972). Military Requirements for Research on Continuous Operations. (Technical Memo 12-72). Aberdeen Proving Grounds, MD: US Army Human Engineering Laboratory.

Task: Continuous operations, generally. A number of papers, with various tasks.

Stressors: Long-term performance, heat, vibration, muscular work, noise.

Notes: Contains good introduction on research needs for continuous operations. Also contains Morgan and Alluisi article on sustained performance.

Holgate, Stanley H. (Date uncertain). The Effects of Combat on Small Unit Cohesion and Bonding. Ft. Bragg, No. Carolina: U.S. Army Medical Research Unit, Walter Reed Army Inst.

Holland, G. (1967). Effects of limited sleep deprivation on performance of selected motor tasks. The Research Quarterly, 39(2), 285-294.

Tasks: 2 short motor tasks: jumping through patterned footsteps and manual manipulation test. One extended duration bicycle ergometer task (duration not stated).

Results: Significant decrement in work performance found in ergometer task following sleep deprivation.

Hoyt, E.P. (1984). The Road to Yongdungpo, from On to the Yalu. Stein and Day.

HQ U.S. Army. (1966). Battlefield Reports: A summary of lessons learned. Volume II. 1 October - 31 December 1965, Vietnam.

HQ U.S. Army. (1967). Battlefield Reports: A summary of lessons learned. Volume III. Vietnam.

Hudgens, G.A., Torre, J.P., Chatterton, R.T., Wansack, S., Fatkin, L., and DeLeon-Jones, F. (1985). Development of Procedures for Obtaining Performance Data Under Conditions Approximating Combat Stress. Proceedings of the Fifth Users' Workshop on Combat Stress. Health Services Command. Fort Sam Houston, TX.

Task: No performance tests proposed. Psychological and physiological data to be gathered.

Stressors: (a) taking exam crucial to medical career; (b) men whose wives face major surgery; and (c) film of crude surgical procedures.

Notes: Description of work-in-progress, no data. The stressors seem to bear an uncertain relationship to combat stressors.

Hudgens, G.A., Torre, J.P., Chatterton, R.T., Wansack, S., Fatkin, L., and Deleon-Jones, F. (1983). Problems in Modeling Combat Stress: A Program to Meet the Challenge. Proceedings of Tenth Biennial Psychology in the DoD Symposium, USAF Academy.

Hudgens, Gerald A., and Fatkin, Linda Torsani. (1986). Sex Differences in Risk Taking: Repeated Sessions on a Computer - Simulated Task. (Technical Memo 2/86). Aberdeen Proving Ground, MD: U.S. Army Human Eng. Lab.

Hughes, A.L., and Goldman, R.f. (1970). Energy cost of "hard work." Journal of Applied Physiology, 29(5), 570-572. (Full Synopsis in Appendix A).

Human Resources Research Center. (1951). Review of Research on Effects of Psychological Stress Upon Performance. (RB-51-28). San Antonio, TX.

Human Resources Research Organization. (1967). Critical Combat Performances, Knowledges, and Skills Required of the Infantry Rifle Platoon Leader: Cover, Concealment, and Camouflage. Alexandria, VA.

Idzikowski, Chris and Baddeley, Alan. (1987). Fear and performance in novice parachutists. Ergonomics, 30(10), 1463-1474.

Ilgen, D., et al. (1967). The Effect of Leadership Style Upon Performance and Adjustment in Volunteer Teams Operating in a Stressful Foreign Environment. Urbana, IL: University of Illinois.

Task: Public health & community development work; leadership of small groups.

Stressors: Being away from home, family, isolation, primitive living conditions, uncooperative natives.

Notes: Not relevant to our interests.

Johns Hopkins University. (1952). Fatigue and Stress Symposium. Operations Research Office. 24-26.

Task: None specified - combat in general.

Stressors: Fatigue and other battlefield stressors.

Notes: Interesting presentations by S.L.A. Marshall and a number of scientists on what is known about fatigue on battlefield. It is concluded that present knowledge of fundamental underlying mechanisms of fatigue & stress is inadequate to define degree of impairment.

Johnson, L.C. (1974). Sleep loss and sleep deprivation as an operational problem. (Rpt No. 74-45). San Diego, CA: US Naval Health Research Center.

Task: General-oriented toward military aviation. A discussion paper.

Stressors: Partial or complete sleep deprivation - primarily in 36-48 hr range.

Notes: A shorter version of #109 (Johnson & Naitoh, 1974). States that short of prolonged sleep loss (greater than 60-72 hrs) it is difficult to state what effects on performance will be. However, sleep loss potentiates other conditions that affect performance.

Johnson, L.C. (1979). Sleep Disturbance and Performance. Advisory Group for Aerospace Research and Development (AGARD), Lecture Series No. 105.

Task: Wilkinson auditory vigilance, continuous counting.

Stressors: Sleep deprivation (up to 40 hrs without sleep.)

Notes: Difficult to find a significant relationship between sleep quality and performance. However, the time of day sleep is obtained and when performance occurs are very important.

Johnson, L.C. (1980). Sleep deprivation and performance. (Report No. 80-21). San Diego, CA: US Naval Health Research Center. (Abbreviated Synopsis in Appendix B).

Johnson, Laverne C. (post 1983). Physiological and Behavioral Responses to the Stress of Sleep Loss. San Diego, CA: Naval Health Research Center. (Abbreviated Synopsis in Appendix B).

Johnson, L.C. and Naitoh, P. (1974). The Operational Consequences of Sleep Deprivation and Sleep Deficit. Advisory Group for Aerospace Research and Development. (Abbreviated Synopsis in Appendix B).

Joint Chiefs of Staff. (1969). Catalogue of War Gaming Models. Wash., DC: Joint War Games Agency, The Pentagon.

Task: N/A.

Stressors: N/A.

Notes: Catalog of war gaming models available in 1969 according to: air defense, air strike, amphibious warfare, anti sub warfare, chemical warfare, ground ops, guerilla warfare, joint/corps ops, mine warfare, supporting arms, tactical nuclear weapons.

Jones, Austin. (1959). The efficiency of utilization of visual information and the effects of stress. Journal of Experimental Psychology, 58(6).

Task: Recognition of visual forms, given different % of information transmission about the forms.

Stressors: Electric shock at different levels.

Notes: Amount of shock stress was monotonically related to efficiency of information utilization and recognition threshold.

Jorgensen, K. and Poulsen, E. (1974). Physiological problems in repetitive lifting with special reference to tolerance limits to the maximum lifting frequency. Ergonomics, 17(1), 31-39.

Stressors: Repeated submaximal lifts with 4 relative loads and 3 relative frequencies.

Tasks: Repetitive lifting from floor to table.

Results: Back muscle strength and oxygen transport system limit lifting. Lifting frequencies presented for relative loads to 50% of maximum lifting capacity.

Kamon, E., and Belding, H. (1971). The physiological cost of carrying loads in temperate and hot environments. Human Factors, 13(2), 153-161. (Abbreviated Synopsis in Appendix B).

Kane, William D. (post-1984). Stress and Aircraft Maintenance Performance in a Combat Environment. Western Carolina University.

Kaplan, Jonathan D., and Crooks, William H. (1980). A Concept for Developing Human Performance Specifications. (Technical Memo 7-80). Aberdeen Proving Ground, MD: U.S. Army, Human Eng. Lab.

Kaufman, Lynn W., Golembe, Evelyn H., SeEVERS, Michael J. (1986). Bibliography of Battle Fatigue Literature. Army Medical Research Unit, Europe.

Task: Not applicable. Unannotated.

Stressors: Combat.

Notes: Further study only if concerned with extreme responses to battle stress.

Karle, R.H. and Bialek, H.M. (1958). The Construction, Validation and Application of a Subjective Stress Scale, Fighter IV. (Study 23). George Washington University, Human Resources Research Office.

Task: Develop easy to use, equal interval, scale of negative affect.

Stressors: Fire fighting, rope bridge, on site at nuclear explosion.

Notes: Exposure to stress showed some shift in affective state toward a fear response, but very little past point of indifference.

Kern, Richard P. (1966). A Conceptual Model of Behavior Under Stress. Implications for Combat Training. George Washington University.

Task: No specific tasks; concern is with ineffective behavior generally.

Stressors: Fear, lengthy exposure to combat.

Notes: Further study if get into more general consideration of stress. Good description of 4 phases of performance degradation as function of time exposed to combat.

- Khalil, T., Genaidy, A., Asfour, S., Vinciguerra, T. (1985). Physiological limits in lifting. Am. Ind. Hyg. Assoc. J., 46(4), 220-224. (Abbreviated Synopsis in Appendix B).
- Kimball, Kent A. (1983). Selected Factors Affecting Aircrew Performance During Sustained Operations. In: AGARD Conference Proceedings No. 338. Sustained Intensive Air Operations: Physiological and Performance Aspects.
- Task: Flying UH-1H helicopter.
 Stressors: 4 hrs of flight in chemical defense clothing (heat stress).
 Notes: Severe physiological effects after only a few hours of flight.
- Kimball, K.A. and Anderson, D.B. (1975). Aviator performance: Biochemical, physiological and psychological assessment of pilots during extended helicopter flight. In: AGARD Conference Proceedings No. 180. The Role of the Clinical Laboratory in Aerospace Medicine.
- King, S.H. Combat Efficiency Ratings Based on 30-59 Days of Observation. (Research Memorandum 54-42). TAGO Personnel Research Branch.
- Task: Rated combat efficiency of Army officers (as a function of duration of observation period).
 Stressors: N/A.
 Notes: Not relevant.
- Kish, Francis B. Col. (1982). Cohesion: The Vital Ingredient for Successful Army Units. Carlisle Barracks, PA: US Army War College.
- Task: N/A. This is a discourse on various factors influencing cohesion.
- Kissel, H. (1956, July). Panic in Battle. Military Review.
- Kjellberg, A. (1977). Sleep deprivation and some aspects of performance. I. Problems of arousal changes. Waking & Sleeping, 1, 139-143.
- Task: N/A - A review and theoretical paper.
 Stressors: Sleep deprivation.
 Notes: Author suggests that effect of sleep deprivation is to potentiate the de-arousing effect of situational variables.
- Kleinhamer, G., and Schaad, G. (1983). Sustained Military Operations With Particular Reference to Prolonged Exercise. In: AGARD Conference Proceedings No. 338 Sustained Intensive Air Operations: Physiological and Performance Aspects.
- Task: Choice RT; driving simulator, pistol shooting; auditory direction discrimination, vigilance, complex psychomotor task.
 Stressors: 72 hrs of sustained operations with only 2 hrs sleep on 2 occasions (after 36 and 60 hrs).

Notes: Reportedly got no performance degradation although no data are presented. Authors attribute their unusual results to the motivation of their subjects, who were paid in proportion to their performance effectiveness.

Kleitman, N. (1963). Sleep and Wakefulness. Chicago: University of Chicago Press.

Kohn, H.R. Toward a Theory of Psychological Stress: An Interim Report. Stead AFB, Nevada: Crew Research Laboratory, Survival Research Field Unit.

Task: Develop insights helpful to Air Force personnel in understanding individual reactions to stress.

Stressors: Failure stress, distraction stress.

Notes: Pure theory.

Kolka, M., Martin, B., and Elizondo, R. (1984). Exercise in a cold environment after sleep deprivation. Eur. J. Appl. Physiol., 53, 282-285. (Abbreviated Synopsis in Appendix B).

Kollar, E.J., Slater Grant, Palmer, James O., Doctor, Richard F. and Mandell, Arnold J. (1966) Stress in subjects undergoing sleep deprivation. Psychosomatic Medicine, 28, 101-113.

Kopstein, F., Siegel, A., Conn, J., Caviness, J., Slifer, W., Ozkaptan, H., and Dyer, F. (1985). Soldier performance in continuous operations: administrative manual for a briefing and seminar for platoon and squad personnel. (Research Note 85-70). U.S. Army Research Institute for the Behavioral and Social Sciences.

Task: This is training course material; articles in appendix are of interest.

Kopstein, Felix F., Siegel, Arthur I., Wilson, Lawrence B., Ozkaptan, Halim. (1979). Human Performance in Continuous Operations: Volume II. Management Guide. Wayne, PA: Applied Psychological Services Inc. (Abbreviated Synopsis in Appendix B).

Kopstein, Felix, Siegel, Arthur, Conn, Joseph, Caviness, James, and Slifer, William. (1985). Soldier Performance in Continuous Operations: Administrative Manual for a Briefing and Seminar for Command and Staff Personnel. (Research Note 85-69). U.S. Army Research Institute for the Behavioral and Social Sciences. (Abbreviated Synopsis in Appendix B).

Kreager, Robert Allen. (1986). The Silent Enemy. Combat Stress Reaction. Maxwell AFB, AL: Air Command and Staff College.

Task: Minimize stress casualties.

Stressors: Combat.

Notes: Historical perspective. Good reference if concerned with the extreme case.

Krueger, G.P., & Jones, Y.F. (1978). U.S. Army aviation fatigue-related accidents, 1971-1977. (USAARL Report No. 79-1). Ft. Rucker, AL: US Army Aeromedical Research Laboratory.

Task: Piloting Army aircraft.

Stressors: Fatigue.

Notes: 4.1% of all accidents reportedly involved fatigue as contributing factor. No clear pattern attributable to sleep loss.

Krueger, G.P., Cardenas-Ortiz, L., and Loveless, C.A. (1985). Human Performance in Continuous/Sustained Operations and the Demands of Extended Work/Rest Schedules: An Annotated Bibliography. (WRAIR-BB-85-1). Washington, DC: Walter Reed Army Institute of Research.

Tasks: Many. 399 references are annotated.

Stressors: Fatigue, sustained work, sleep deprivation and many others.

Notes: Key document. Much useful information in the annotations themselves.

Krueger, Gerald P., Armstrong, Richard N., and Ciaco, Ronald R. (1985). Aviator performance in week-long extended flight operations in a helicopter simulator. Psychonomic Society, Inc. In: Behavior Research Methods, Instruments, & Computers, 17(1). (Abbreviated Synopsis in Appendix B).

Krueger, Gerald P. (post, 1985). Problems of Using Sleep Research Techniques in the Field. Walter Reed Army Institute of Research.

Krueger, Gerald P., and Fagg, James N. (1981). Aeromedical Factors in Aviator Fatigue, Crew Work/Rest Schedules and Extended Flight Operations: An Annotated Bibliography. Fort Rucker, AL: Army Aeromedical Research Lab.

Task: Various - mostly related to piloting aircraft.

Stressors: Extended ops, time zone transitions, irregular sleep.

Notes: Some useful studies, but work times generally shorter than those of interest. Most tasks different also. 223 abstracts. Key critique by Bartlett (see pg 19-20).

Krueger, Gerald, Balkin, Thomas, Belenky, Gregory, Headley, Don., and Solick, Robert. (1986). Effects of continuous operations (CONOPS) on soldier and unit performance. Phase II: Strategies for sustaining the soldier in CONOPS. Fort Leavenworth, KS: US Army Combined Arms Combat Developments Activity.

Task: Land combat - CONOPS, A manual of advice on how to manage soldiers during CONOPS.

Stressors: Little or no sleep.

Notes: Key document reflecting WRAIR and ARI thinking on CONOPS. Companion to Vol I which has more data.

Kubala, Albert L., and Warnick, William L. (1979). A Review of Selected Literature on Stresses Affecting Soldiers in Combat. (ARI Technical Report TR-79-A 14). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Kugelmass, S. (1963). Effects of Three Levels of Realistic Stress on Differential Physiological Reactivities. Jerusalem, Israel: Hebrew University of Jerusalem, Israel.

Task: Deception, during an interrogation.

Stressors: Assessment by observers of whether career was successful or not.

Notes: Not relevant. Aimed at assessing lie detection technology.

Kurka, M.I. (1962a). Human Factors in War Gaming. I. (CORG-SP-153). Alexandria, VA: Generalized System Combat Operations Research Group.

Task: Appropriate model group behavior in war games.

Stressors: Non-specific.

Notes: Conceptual model of human factors systems is presented. Theoretical considerations. May be useful during modeling phase.

Kurka, M.I. (1962b). Human Factors in War Gaming. II. Morale and Unit Effectiveness. (CORG-SP-154). Alexandria, VA: Combat Operations Research Group.

Task: Appropriately model unit utility in combat war games.

Utility is a function of morale, group cohesion.

Stressors: N/A

Notes: Method of modelling effects of group morale in war games is presented. May be of interest during modelling phase.

Lamb, Jerry C. (1976). Preliminary Test of Human Performance Prediction System (HUPPS). (Technical Report 5347). New London, CN: Naval Underwater Systems Center.

Task: Sonar repair.

Stressors: N/A.

Notes: This report not relevant.

Landstrom, Ulf and Lofstedt, Per Eng, M. (1987, February). Noise, Vibration and Changes in Wakefulness During Helicopter Flight. Aviation, Space, and Environmental Medicine.

Task: Piloting helicopters (no performance measures).

Stressors: Noise, vibration, flight duration (2 or 4 hours).

Lange, C.J., and Jacobs, O. (1960). Leadership in Army Infantry Platoons. Study II. (Res. Rpt. 5). Washington, DC: Human Resources Research Office.

Lauterbach, C.G., and Vielhaber, D.P. (1966). Rifle Performance Under Conditions of Stress. (Final Report 66-1). West Point, New York: U.S. Army Hospital.

Task: Rifle fire on range.

Stressors: Reaction to authority, test anxiety, group pressure.

Notes: No effects of the mild stressors used on performance.

Lavie, Peretz. (1986). Twenty-Four Hour Structure of Vigilance Under Prolonged Sleep Deprivation: Relationship with Performance. Army Research Institute for the Behavior and Social Sciences.

Task: One- and two-handed tracking tasks.

Stressors: 36 hrs partial sleep deprivation with very short cycles (7 and 13 min) of sleep and performance.

Notes: Very unique work/sleep schedule with virtually no relevance to real world problems.

Lazarus, R.S., Deese, J.E., and Osler, S.F. (1952). The Effects of Psychological Stress upon Performance. Psychological Bulletin, 49(4), Part I.

Task: Various - mostly laboratory. A review article.

Stressors: Failure, excessive task demands.

Notes: Review article that concludes that we don't know near enough.

Lazarus, R.S. (1966). Psychological Stress and the Coping Process. New York: McGraw-Hill.

Lees, M.A., Stone, L.W., Jones, H.D., Kimball, K.A., & Anderson, D.B. (1979). The measurement of man-helicopter performance as a function of extended flight requirements and aviator fatigue. (Report No. 79-12). Fort Rucker, AL: Army Aeromedical Research Lab.

Legg, S.J., and Mahanty, A. (1985). Comparison of five modes of carrying a load close to the trunk. Ergonomics, 28(12), 1653-1660. (Abbreviated Synopsis in Appendix B).

Legg, S. and Pateman, C. (1984). A physiological study of the repetitive lifting capabilities of healthy young males. Ergonomics, 27(3), 259-272. (Full Synopsis in Appendix A).

Legg, S., and Patton, J. (1987). Effects of sustained manual work and partial sleep deprivation on muscular strength and endurance. Eur. J. Appl. Physiol., 56, 64-68. (Full Synopsis in Appendix A).

Lau, John R., Manning, Frederick J., and O'Donnell, Vincent M. (Post 1984). Pharmacological Optimization of Performance: Memory and Cognition. Wash, DC: Walter Reed Army Institute of Research.

Levi, L. (1972). 7 Psychological and physiological reactions to and psychomotor performance during prolonged and complex stressor exposure. In L. Levi (Ed.), Stress and Distress in Response to Psycho-social Stimuli. Oxford: Pergamon Press, 119-142. (Full Synopsis in Appendix A).

Levine, L., Evans, W.J., Winsmann, F.R., and Pandolf, K.B. (1982). Prolonged self-paced hard physical exercise comparing trained and untrained men. Ergonomics, 25(5), 393-400. (Full Synopsis in Appendix A).

Lidz T. (1946). Psychiatric Casualties from Guadalcanal: A Study of Reactions to Extreme Stress. Psychiatry, 9, 193-213.

Task: N/A.

Stressors: Extended exposure to extremely adverse combat conditions.

Lind, A. (1963). Physiological effects of continuous or intermittent work in the heat. J. Appl. Physiol., 18(1), 57-60. (Abbreviated Synopsis in Appendix B).

Link, B.D., and Shapiro, H.D. (1979). The Small Force Engagement Range (SFER) and its Application to the Gathering of Behavioral Data. (SAND-79-0447C). Albuquerque, NM: Sandia Laboratories.

Lisper, Hans-Glof, and Kjellberg, Anders. (1972). Effects of 24-hour sleep deprivation on rate of decrement in a 10-minute auditory reaction time task. Journal of Experimental Psychology.

Lubin, A. (1967). Performance Under Sleep Loss and Fatigue. In Sleep and Altered States of Consciousness. Monograph of Assoc. for Research in Nervous and Mental Disease. VOL XLV, 506-513. Baltimore: Williams and Wilkins Co.

Lubin, A., Hord, D., Tracy, M.L., and Johnson, L.C. (1975). Effects of Exercise, Bedrest and Napping on Performance Decrement During 40 Hours. San Diego, CA: Naval Health Research Center, San Diego, CA. (Abbreviated Synopsis in Appendix B).

Luby, E.D., Frohman, C.E., Grisell, J.L., Lenzo, J.E., & Gottlieb, J.S. (1960). Sleep deprivation: Effects on behavior, thinking, motor performance, and biological energy transfer systems. Psychosomatic Medicine, 22, 182.

Lunsetter, Wayne, Glynn, Michael Horton, Donald, Watts, Robert, and Peterson, Bruce. (1979). Army Aviation Personnel Requirements for Sustained Operations (AAPRSO) Study; Volume IV. Appendices J-L. (AD046468). Fort Rucker, AL: Army Aviation Agency Center.

Task: Various day and night combat missions.

Stressors: High mental workload; high number of takeoffs, landings; instrument flying.

Notes: Appendix L summarizes results of surveys taken concerning pilot opinion of conditions producing fatigue. No performance data.

Mackie, Robert R., and Miller, James C. (1978). Effects of hours of service, regularity of schedules, and cargo loading on truck and bus driver fatigue. (Report No. 1765-F). Goleta, CA: Human Factors Research Inc.

Notes: Amount of fatigue and performance degradation tied to length of time driving, irregularity of schedules and amount of physical work performed.

Mackie, Robert R., Wylie, C. Dennis, and Smith, Malcolm. (1985). Stress and sonar operator performance: A literature review and operator survey. Goleta, CA: Human Factors Research Division, Essex Corp.

Maginnis, Robert L. (1984, December). Battle Stress: Are we prepared? Armor.

Magner, G. (1968). Critical Combat Performances, Knowledge, and Skills Required of the Infantry Rifle Platoon Leader, Defensive operations. (AD704971). Fort Ord, CA: Human Resources Research Laboratory.

Mairiaux, P., Libert, J., Candas, V., and Vogt, J. (1984). Physiological and perceptual responses to cyclic heat stress variations. Aviation, Space, and Environmental Medicine, 55, 935-940.

Malmo, R.B., & Surwillo, W.W. (1960). Sleep deprivation: Changes in performance and physiological indicants of activation. Psychological Monographs, 74(15). (whole No. 502).

Task: Simple tracking, with continuous performance feedback.

Stressors: 60 hrs without sleep.

Notes: Study of interest because of feedback feature aimed at countering sleep loss effects. Both subjective & physiological measures showed strong fatigue effects, performance results were equivocal, probably because performance sessions were widely spaced in time. Only 3 S's.

Mangelsdorff, A. David, King, James M., and O'Brien, Donald E. (1986). Proceedings, Fifth Users' Workshop on Combat Stress. Fort Sam Houston, TX: U.S. Army Health Services Command.

Task: Various - this is a collection of papers, only 2 or 3 of which are of interest.

Stressors: Sustained operations.

Notes: Conclusions & recommendations included on amount of sleep required for sustained operations (pp 175 & following); also data on degradation of tank crew performance in MOPP gear (pp 151 ff).

Manners, Geoffrey. (1983, January 18). Coping with Stress on the Battlefield. Jane's Defense Weekly.

Manning, Frederick J. (1985). Human factors in sustaining high rates of artillery fire. Ft. Detrick, MD: U.S. Army Medical Research & Development Command.

Manning, Frederick J. and Ingraham, Larry H. (1981, June). Who Melts, When, and Why? Field Artillery Journal, p. 13.

- Marks, J.W. (1961). Human Factors Support of Requirements for Continuous Operations. Department of Army Report, 15th Annual Army Human Factors R&D Conference.
- Marshall, S.L.A. (1947). Men against Fire. New York: William Morrow.
- Task: Getting soldiers to fire their weapons, various others.
 Stressor: Threat of enemy fire.
 Notes: Some historical observations (data) that should be considered when modeling.
- Martin, B. (1981). Effect of sleep deprivation on tolerance of prolonged exercise. Eur. J. Appl. Physiol., 47, 345-354. (Abbreviated Synopsis in Appendix B).
- Martin, B., and Gaddis, G. (1981). Exercise after sleep deprivation. Medicine and Science in Sports and Exercise, 13(4), 220-223.
- Martin, B., and Hsiun-ing Chen (1984). Sleep loss and the sympatho-adrenal response to exercise. Medicine and Science in Sports and Exercise, 16(1), 56-59.
- Stressors: 50 hrs sleepless period; treadmill walking.
 Results: Sleep loss reduced time to exhaustion by 20%. Sleep loss does not diminish the peripheral sympathetic nervous system response to exercise, although it reduces exercise tolerance through unexplained mechanisms.
- McCord, H.H., and Abitz, F.W. (1964). Use of Suggestion in Psychological Warfare, In Proceedings of First Symposium on Psychological Effects of Non-Nuclear Weapons. Volume II. (AD350528). Eglin, AFB, Florida.
- McKay, John B., Cianci, Salvatore, Hall, Charles E. and Taylor, John E. (1959). Some Factors Which Have Contributed to Both Successful and Unsuccessful American Infantry Small-Unit Actions. Research Memo 13, (AD260994). Ft. Benning, GA: U.S. Army Infantry Human Research Unit.
- McMurray, R., and Brown, C. (1984). The effect of sleep loss on high intensity exercise and recovery. Aviation, Space, and Environmental Medicine, 55, 1031-1035. (Abbreviated Synopsis in Appendix B).
- Mears, Jillian D., and Cleary, Patrick J. (1980). Anxiety as a factor in underwater performance. Ergonomics, 22(6), 549-557.
- Meddis, R. (1982). Cognitive dysfunction following loss of sleep. In: A. Burton (Ed.) Pathology and Psychology of Cognition. London: Methuen. 225-252.
- Meeland, T., and others. (1969). A Review of Some Ground Combat Simulation Models. Aberdeen Proving Ground, MD: Army Material Systems Analysis Agency.

- Moeland, Tor, Egbert, Robert L., and Miller, Irwin. (1957). Field Stress: A preliminary study of its structure, measurement, and relationship to combat. Alexandria, VA: George Washington Univ.
- Human Resources Research Office. (Abbreviated Synopsis in Appendix B).
- Meerlo, J.H.M. (1956). Mental Danger, Stress and Fear. Journal of Nervous and Mental Disease. 123.
- Michel, R.R., and Solick, R.E. (1983). Review of Literature on the Effects of Selected Human Performance Variables on Combat Performance. Field Unit Working Paper FLV-FU-83-4. Ft. Leavenworth: U.S. Army Research Institute for the Behavioral and Social Sciences. (Abbreviated Synopsis in Appendix B).
- Milgram, Norman (Ed). (1986). Stress and Coping in Time of War: Generalizations from the Israeli Experience. New York: Brunner/Mazel, Tel-Aviv University.
- Miller, J., Farlow, D., and Seltzer, M. (1977). Physiological analysis of repetitive lifting. Aviation, Space, and Environmental Medicine, 48(10), 984-988.
- Miller, J.C., and Narvaez, A. (post 1983). A comparison of Two Subjective Fatigue Checklists. Brooks AFB, TX: USAF School of Aerospace Medicine.
- Miller, J.G. (1953). The Development of Experimental Stress Sensitive Tests for Predicting Performance in Military Tasks. (Report 1079). Personnel Research Branch, Adjutant General's Office.
- Task: Critical flicker fusion, tremblemeter, cancellation of C's, word fluency.
- Stressors: 8000 cps, 90 dB noise while taking tests.
- Notes: Non-relevant selection of tests and stressor.
- Miller, George, and Bonder, Seth. (1982). Human Factors Representations for Combat Models. (Report No. VRI-ARI-6 FR82-1). Ann Arbor, MI: Vector Research, Incorporated.
- Miller, Robert B. (1971). Development of a Taxonomy of Human Performance: Design of a Systems Task Vocabulary. American Institutes for Research.
- Minard, D., Grayeb, G.J., Singer, R.C., and Kingston, J.R. (1961). Heat Stress During Operation Banyan Tree I. (Report No. 5). Bethesda, MD: Naval Medical Research Institute.
- Mital, A., Karwowski, W., Mazouz, A., and Orsagh, E. (1986). Prediction of maximum acceptable weight of lift in the horizontal and vertical planes using simulated job dynamic strengths. Am. Ind. Hyg. Assoc. J., 47(5), 288-292.
- Moog, Rudolf. (1987). Optimization of shift work: physiological contributions. Ergonomics, 30(9), 1249-1259.

Morgan, B.B. (1974). Effects of continuous work and sleep loss in the reduction and recovery of work efficiency. American Industrial Hygiene Association Journal, 35, 13-20. (Abbreviated Synopsis in Appendix B).

Morgan, B.B. Jr., Coates, G.D., Brown, B.R., and Alluisi, E.A. (1973). Effects of Continuous Work and Sleep Loss on the Recovery of Sustained Performance. HEL Technical Memo 14-73, AD769933. Aberdeen Proving Grounds, MD: US Army Human Engineering Laboratory. (Abbreviated Synopsis in Appendix B).

Morgan, B.B., and Alluisi, E.A. (1972). Applicability of Research on Sustained Performance, Ensurance, and Work-Rest Scheduling to the Development of Concepts and Doctrine of Continuous Operations. Technical Memo 12-72. In D. Hodge (Ed.) Military Requirements for Research on Continuous Operations. Proceedings of a Conference Held at Texas Tech Univ, Lubbock, TX, 28-29 Sept 1971. Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

Morgan, Ben B. Jr., and Coates, Glynn D. (Eds.). (1974). Sustained Performance and Recovery During Continuous Operations. Interim Tech (Report No. ITR-74-2). Arlington, VA: Organizations and Systems Research Lab., U.S. Army Research Institute for Behavioral & Social Sciences, Dept. of Army.

Task: Multiple-task performance battery.

Stressors: Up to 48 hrs of continuous synthetic work.

Morgan, Ben B. Jr., Brown, Bill R., and Alluisi, Earl A. (1974). Effects on Sustained Performance of 48 Hours of Continuous Work and Sleep Loss. Human Factors, 16(4), 406-414.

Task: Multiple-task performance battery.

Stressors: 48 hrs continuous work and sleep loss.

Notes: Decrements as % of baseline reported. Also recovery following 24 hrs of rest.

Moskin, J.R. (1982). Ammunition Hill. Ballantine Books.

Moskin, J.R. (1982). The Tanks - The Crucial Battle. Among Lions. Ballantine Books.

Mullaney, D.J., Kripke, D.R., & Fleck, P. (1981). Sleep loss effects on continuous sustained performance. (Technical Report #1). San Diego: University of California, Department of Psychiatry. (Full Synopsis in Appendix A).

Mullaney, D.J., Kripke, D.F., Fleck, P.A., & Okudaira, N. (1983). Effects of sustained continuous performance on subjects working alone and in pairs, Perceptual and Motor Skills, 57, 819-832.

Task: Tracking, visual memory, addition.

Stressors: Nearly continuous task performance for 42 hrs.

Notes: All subjects showed substantial deterioration whether working alone or in pairs. Unfortunately the experimental set-up did not lend itself to mutual support of paired S's who largely ignored each other. Deterioration, confusion & hallucinations.

Mullaney, Daniel J., Fleck, P.A., Okudaria, N. and Kripke, D.F. (1985). An automated system for administering continuous workload and for measuring sustained continuous performance. The Psychonomic Society, Inc. In Behavior Research Methods, Instruments & Computers, 17(1).

Task: Tracking, pattern memory, addition.

Stressors: 42 hrs continuous performance except for 6 1-hr naps or 1 6-hr nap.

Notes: Authors conclude their method of continuous computerized tasking of subjects leads to more rapid performance deterioration than intermittent work paradigms.

Murrell, K. (1965). A classification of pacing. Intl. J. of Prod. Resch., 4(1), 69-74.

Myles, W.S., Eclache, J.P., and Boaury, J. (1979, September). Self-pacing during sustained, repetitive exercise. Aviation, Space and Environmental Medicine, 921-924. (Full Synopsis in Appendix A).

Myles, W.S., and Romet, T.T. (1986). Combat Engineer Effectiveness in Sustained Operations. Downsview, Ontario: Defence and Civil Institute of Environmental Medicine. (Abbreviated Synopsis in Appendix B).

Naitoh, P. (1969). Sleep Loss and Its Effects on Performance. (Report No. 68-3). San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

Task: Various

Stressors: Complete sleep deprivation; partial sleep deprivation.

Notes: Highly comprehensive review. Conclusions about how sleep loss effects vary with duration of task, knowledge of results, difficulty of task, task pacing, subject's proficiency, task complexity, memory requirements, interest level, motivation, personality (etc.).

Naitoh, P. (1976). Sleep deprivation in human subjects: a reappraisal. Waking & Sleeping, 1, 53-60.

Task: Various - this is a review of the state of the art in sleep deprivation research.

Stressors: Sleep deprivation

Notes: Has important observations on why field studies of sleep deprivation do not always show expected (deleterious) effects.

Naitoh, P., and Angus, R.G. (1987). Napping and Human Functioning During Prolonged Work. San Diego, CA: Naval Health Research Center.

Naitoh, P., and Englund, C.E. (1983). Extending Human Effectiveness During Sustained Operations through Sleep Management. (Report No. 83-13). San Diego, CA: Naval Health Research Center. (Abbreviated Synopsis in Appendix B).

Naitoh, P., Englund, C.E., and Ryman, D.H. (1987). Sustained Operations: Research Results. San Diego, CA: Naval Health Research Center. (Full synopsis in Appendix A).

Naitoh, P., Englund, C.E., Ryman, D.H., and Hodgdon, J.A. (1984). Effect of Physical Work and Sleep Loss on Recovery Sleep. (Report No. 84-30). Bethesda, MD: Naval Medical Research and Development Command.

Task: Cognitive tasks at a computer terminal.

Stressors: 17 hr continuous work periods, treadmill in full combat gear.

Notes: Physiological data only.

Naitoh, Paul. (1981). Circadian Cycles and Restorative Power of Naps; in The Twenty-Four Hour Workday: Proceedings of a Symposium on Variations in Work-Sleep Schedules. Cincinnati, OH: U.S. Dept. of Health & Human Services.

Task: Search for letters; tapping tasks; choice RT, short term memory.

Stressors: 45-53 hrs of work without sleep.

Notes: Recuperative power of naps dependent on: (1) prior hours of wakefulness; (2) time of day taken; and (3) duration of nap.

Naitoh, Paul and Townsend, Richard E. (1970). The Role of Sleep Deprivation Research in Human Factors. Human Factors, 12(6), 575-585. (Abbreviated synopsis in Appendix B).

Naitoh, Paul, Englund, Carl, and Ryman, David H. (1986). Sleep Management in Sustained Operations: User's Guide. (AD173050). San Diego, CA: Naval Health Research Center. (Full synopsis in Appendix A).

Nanji, Amin A., Greenway, Donald C., and Bigdeli, M. (1985). Relationships Between Growth Hormone Levels and Time Spent by Soldiers in an Active War Zone. Ottawa, Canada: Department of Laboratory Medicine, Ottawa General Hospital and University of Ottawa, also University of Tehran, Tehran, Iran.

National Technical Information Service (Ed.). (1983). Stress Factors on Pilot Performance. Springfield, VA.

Task: Few of these studies involved task performance.

Stressors: Long flight operations, others.

Natkiel, Richard. (1982). Atlas of 20th Century Warfare. New York: Gallery Books.

NATO Defence Research Group. (1983). Proceedings of the 24th DRG Seminar on the Human as a Limiting Element in Military Systems. Volume I, Brussels, Belgium: NATO Defence Research Group.

Naylor, J.C. (1964). A Proposed Method for Determining the Psychological Effects of Weapons. In Proceedings of the First Symposium of the Psychological Effects of Non-Nuclear Weapons - Volume I, Norman, OK: University of Oklahoma Research Institute.

Task: N/A

Stressors: Fear (relative) of various weapons.

Notes: Weapons effect considered to be dependent on both physical and psychological factors. Combat experience greatly modifies fear response.

Neff, K.L., and Solick, R.E. (1983). Military Experts' Estimates of Continuous Operations Performance (or Close but no Cigar). (Technical Report 600). Fort Leavenworth, KS: Army Research Institute Field Unit.

Task: Estimated performance degradation base on written description of field tests.

Stressors: 48 hrs to 5 days of continuous operations.

Notes: Important study. Raises serious doubts about experts' estimations, but the performance measures also leave doubts.

Newman, R.A. (1964). Combat Fatigue: A Review of the Korean conflict. Military Medicine, 129(10).

Nicholson, A.N., Pascoe, P.A., Roshra, T. Roth, T. Spencer, M.B., Stone, B.M. & Zorick, F. (1985). Sustained performance with short evening and morning sleeps. Aviation, Space and Environmental Medicine, 56, 105-114.

Task: Digit symbol substitution; letter cancellation, logic, arithmetic, RT, visuo-motor coordination, vigilance, memory.

Stressors: Variety of displaced sleep patterns.

Notes: Evening sleep (1800-2200) improved performance during an overnight period of wakefulness.

Nicholson, Anthony N. (1987). Sleep and Wakefulness of the Airline Pilot. Washington, DC: Aerospace Medical Assn.

Nicholson, Anthony N., Stone, Barbara M., Borland, Richard G., and Spencer, Michael B. (1984). Adaptation to Irregularity of Rest and Activity. Washington, DC: Aerospace Medical Association.

Task: Choice RT, serial memory, vigilance, manikin identification.

Stressors: Shifting periods of work and sleep, with respect to 24-hr clock, for 9 days.

Notes: Interest was on irregularity of sleep, but subjects permitted 8 hrs of sleep in every 24.

NIOSH. (1981). Work practices guide for manual lifting. (NIOSH Publication No. 81-122). Cincinnati, OH: US Department of Health and Human Services. (Abbreviated Synopsis in Appendix B).

No authors. (1952, December). A Study of Combat Stress in Korea. ORO-T-41 (FEC), John Hopkins University, Operations Research Office.

No authors. (1953, March). Symposium on Stress (16-18 March 1953). Washington, DC: Army Medical Service Graduate School.

Task: N/A.

Stressors: Various, including combat.

Notes: Papers, mostly by M.D.'s, on medical and psychological aspects of stress. Virtually no data. Nothing related to performance.

No authors. (1962, December). Concept of close combat during night operations and other conditions of low visibility. Quantico, VA: U.S. Marine Corps.

Norton, Royan. (1970). The Effects of Acute Sleep Deprivation on Selective Attention. British J. Psychology, 61, 157-161. (Abbreviated synopsis in Appendix B).

National Technical Information Service. (1983, September). Fatigue effects on human behavior and performance. NTIS.

Stressors: Various

Notes: 305 citations, 1964-1983. Very few of interest/relevance, other than some previously found in other sources.

O'Brien, James, and Smith, H. Stuart. (1983). Soldier Dimension in Battle. (AD127956). Virginia Beach, VA: A.E. McMichael & Associates.

Task: None - an armchair discussion; very general, sociological.

O'Donnel R.D., and Eggemeier, F.T. (1983). Conceptual Framework for the Development of Workload Metrics in Sustained Operations. In: AGARD Conference Proceedings No. 338 Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Not applicable. This is a position paper on research needed to standardize workload assessment in sustained operations.

Stressors: Sustained operations.

Notes: May be useful to review prior to field data collection.

O'Donnell, Vincent M. (post 1984). Pharmacological Optimization of Performance: Sleep and Arousal. Wash., DC: Walter Reed Army Institute of Research.

Olley, Randy and Krauss, Herber H. (1974). Variables Which May Influence the Decision to Fire in Combat. Journal of Social Psychology.

Task: Fill out 32 item questionnaire reflecting likelihood of shooting under various circumstances.

Stressors: None, or imagined only.

Notes: Used non-soldiers as subjects!

Opstad, P.K., Ekanger, R., Nummestad, M., & Raabe, N. (1978). Performance, mood, and clinical symptoms in men exposed to prolonged, severe physical work and sleep deprivation. Aviation, Space, and Environmental Medicine, 49(9), 1065-1073. (Full Synopsis in Appendix A).

Orr, David B. (1964). Research on Behavior Impairment Due to Stress: An Experiment in Long-Term Performance. Journal of Experimental Psychology, 68, 94-102. (Abbreviated Synopsis in Appendix B).

Oshima, Masamitsu. (1981). The mechanism of mental fatigue. In Selvendy, Gavriel and Smith, M.J. (Eds.) Machine Pacing and Occupational Stress. London: Taylor and Francis. (Abbreviated Synopsis in Appendix B).

Oswald, Dr. Ian. (1969). Sleep and sleep deprivation. Royal Society of Medicine - Proceedings, 62.

Task: N/A - clinical paper on paradoxical sleep, and effects of various drugs.

Stressors: N/A.

Notes: Not relevant to present interests.

Pachella, R.G. (1976). Intellectual Performance Under Stress. University of Michigan.

Task: Information processing generally - 9 laboratory tasks used.

Stressors: Speed stress, information overload, anxiety (trait).

Notes: 10 yrs of research at Univ. of Michigan. A good source if wish to examine information processing in detail under time/work load pressure.

Page, Monte, Goff, Clinton, and Palmer, J.D. (1964). The Psychological Effects of Non-Nuclear Weapons: A Bibliography With Selected Abstracts, Volume I. Norman, OK: University of Oklahoma Research Institute.

Task: Coping with the stress of combat.

Stressors: Bombardment, small arms fire, indirect fire, catastrophes.

Notes: Contains both annotated and unannotated bibliographies.

Page, Monte; Goff, Clinton; Palmer, J.D., Jett, Wayne; and Gustafson, L.M. (1964). Prior art in the psychological effects of weapons systems. In Proceedings of the First Symposium on the Psychological Effects of Non-Nuclear Weapons. Univ. of Oklahoma.

Task: N/A - a literature review.
Stressors: Fear associated with enemy fire.
Notes: Fig 1 is conceptual diagram linking weapon variables, situational variables, etc to behavior.

Palmer, J.D., Dahlke, A.E., Terry, R.A., et al. (1966). Investigation of Psychological Effects of Non-Nuclear Weapons for Limited War, Volume I. Eglin Air Force Base, FL: Air Force Systems Command.

Task: Determine psychological effects of non-nuclear weapons.
Stressors: Weapons with different signatures, various situational variables.

Notes: Important study. Good assessment of literature. Good conceptual model (net of variables). Interesting formulation of Psychological Index.

Pandolf, K., Bursse, R., and Goldman, R. (1977). Role of physical fitness in heat acclimatization, decay and reinduction. Ergonomics, 20(4), 399-408.

Pandolf, K.B., Givoni, B., and Goldman, R.F. (1977). Predicting energy expenditure with loads while standing or walking very slowly. Journal of Applied Physiology, 43(4), 577-581. (Full Synopsis in Appendix A).

Pandolf, K., Stroschein, L., Drolat, L., Gonzalez, R., and Sawka, M. (1986). Prediction modeling of physiological responses and human performance in the heat. Comput. Biol. Med., 16(5), 319-329. (Full Synopsis in Appendix A).

Pasnau, R.O., Naith, P., Stier, S., and Kollar, E.J. (1968). The psychological effects of 205 hours of sleep deprivation. Archives of General Psychiatry, 18, 496-505. (Abbreviated Synopsis in Appendix B).

Patton, J., Murphy, M., and Frederick, F. (1985). Maximal power outputs during the Wingate anaerobic test. Int. J. Sports Med., 6, 82-85.

Perelli, L.P. (1980). Fatigue Stressors in Simulated Long-Duration Flight. Effects on Performance, Information Processing, Subjective Fatigue and Physiological Cost. Brooks AFB: USAF School of Aerospace Medicine. (Abbreviated Synopsis in Appendix B).

Peters, Ralph H. Jr. (1983, December). Battlefield Initiative. Army Magazine.

Petersen, Peter B. (1972). Fatigue in Sustained Tactical Operations. Ft. Sam Houston, TX: Army Combat Developments Command Medical Service Agency. (Abbreviated Synopsis in Appendix B).

Pew, R.W., Fachrer, C.E., Baron, S. and Miller, D.C. (1977). Critical Review and Analysis of Performance Models Applicable to Man/Machine Systems Evaluation. (AFOSR-TR-77-0520). Cambridge, MA: Bolt, Beranek, and Newman, Inc.

Pierrynowski, M., Norman, R., and Winter, D. (1981). Mechanical energy analysis of the human during load carriage on a treadmill. Ergonomics, 24(1), 1-14.

Pierrynowski, M., Winter, D., and Norman, R. (1981). Metabolic measures to ascertain the optimal load to be carried by man. Ergonomics, 24(5), 393-399. (Abbreviated Synopsis in Appendix B).

Pleban, Robert J., and Thomas, Debra A. (1985). Physical Fitness as a Moderator of Cognitive Work Capacity and Fatigue Onset under Sustained Combat-Like Operations. The Psychonomic Society. In Behavior Research Methods, Instruments, & Computers, 17(1). (Abbreviated Synopsis in Appendix B).

Polzella, D.J. (1974). The effect of sleep-deprivation on short-term recognition memory. (USAF OSR Report No. TR-74-329). Ann Arbor, MI: Univ. of Michigan, Human Performance Center.

Possenti, R.G. (1967). Human Performance Under Conditions of Cold and Stress: Report on Unit Effectiveness. AAL-TR-66-11. Fort Wainwright, AK: Arctic Aeromedical Laboratory.

Task: Field maneuvers over 15 day period.

Stressors: Isolation, cold.

Notes: Many deficiencies in this study.

Price, G. Richard. Hazard From Intense Low-Frequency Acoustic Impulses. Technical Memo 14-86. Aberdeen Proving Ground, MD: U.S. Army, Human Eng. Lab.

Rachman, S. (1983). Fear and Courage among Military Bomb-Disposal Operators. Advances in Behaviour Research & Therapy, 4(3), 175. Vancouver, Canada: Univ. British Columbia.

Randle, I., and Legg, S. (1985). A comparison of the effects of mixed static and dynamic work with mainly dynamic work in hot conditions. Eur. J. Appl. Physiol., 54, 201-206. (Full Synopsis in Appendix A).

Rauch, T.M. Banderet, L.E., Tharion, W.J., Munro, I., and Lussier, A.R. (1986). Factors Influencing the Sustained Performance Capabilities of 155mm Howitzer Sections in Simulated Conventional and Chemical Warfare Environments. Natick, MA: Army Research Inst of Environmental Medicine. (Full Synopsis in Appendix A).

Ray, James T., Martin, O. Edmund Jr., and Alluisi, Earl A. (1961). Human Performance as a Function of the Work-Rest Cycle. National Academy of Sciences - National Research Council.

Task: Work in general - this is a review article.

Stressors: Hours of continuous performance.

Notes: Authors conclude that number of generalizations relating to optimal work-rest schedule are limited. Literature from 1894-1960 reviewed.

Rayman, D.H., Naith, P., and Englund, C.E. (1987). Perceived exertion under conditions of sustained work and sleep loss. (Report No. 97-9, AD-A182 148). San Diego, CA: Naval Health Research Center. (Full Synopsis in Appendix A).

Reid, D.D. (1979). Fluctuations in Navigator Performance During Operational Sorties. In: Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1945 report).

Reid, D.D. (1979). Some Measures of the Effect of Operational Stress on Combat Crews. In: Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1944 report).

Reid, D.D. (1979). The Historical Background to Wartime Research in Psychology and Psychiatry in the Royal Air Force. In: Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press.

Reid, D.D. (1979). The Influence of Psychological Disorder on Efficiency in Operational Flying. In Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1942 report).

Rosa, R.R., Bonnett, M.H., and Warm, J.S. (1983). Recovery of performance during sleep following sleep deprivation. Psychophysiology, 20, 152-159.

Rowland, D. (1985). Assessments of Combat Degradation. Surrey, UK: Defence Operational Analysis Establishment.

Notes: Historical data.

Rutenfranz, J., Aschoff, J., & Mann, H. The effects of a cumulative sleep deficit, duration of preceding sleep period and body-temperature on multiple choice reaction time. In W.P. Colquhoun (Ed.), Aspects of Human Efficiency, English Universities Press, 217-229.

Samn, Sherwood W., and Perelli, Layne P. (1982). Estimating Aircrew Fatigue: A Technique with Application to Airlift Operations. (Final Report Oct. 80 - Sept. 81, 29p). Brooks AFB, TX: School of Aerospace Medicine.

Sanders, A.F. (1983). Some Issues in Research on Effects of Sustained Work and Sleep Loss on Performance. In: AGARD Conference Proceedings No. 338 Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Various RT tasks, including some using degraded, incompatible and temporally uncertain stimuli.

Stressors: 24 hrs sleep loss.

Notes: Very short (20 min) tests, infrequently given. However, of interest in that stimuli that were perceptually degraded, temporally uncertain, or called for incompatible responses produced the greatest degradation in reaction time.

Sanford, James P., Steinkarchner, Raymond E., Cantrell, George K., Trimble, Ralph W., and Hartman, Bryce O. (1971). Alertness, Fatigue, and Morale of Air Force Sentries. Brooks AFB, TX: Aerospace Medical Div. (Full synopsis in Appendix A).

Sargent, Robert G. (1985). An expository on verification and validation of simulation models. Syracuse, NY: Syracuse University.

Sawka, M., Toner, M., Francesconi, R., and Pandolf, K. (1983). Hypohydration and exercise: effects of heat acclimation, gender, and environment. Journ. Appl. Physiol., 55(4), 1147-1153.

Schein, E.H. (1957). The effects of sleep deprivation on performance in a simulated communication task. J. Appl. Psychol., 41, 247-252. (Abbreviated Synopsis in Appendix B).

Schults, Duane P. (1971). Panic in the Military. (Technical report). Charlotte: Dept. of Psychology, University of North Carolina.

Schwalm, R.C., Crumley, L.M., Coke, J.S., and Sachs, S.A. (1981). Description of the ARI Crew Performance Model: A final report. (Working Paper FSFU 80-6). US Army Research Institute for the Behavioral and Social Sciences.

Task: Operating M109A1 howitzer. (It's claimed that the model also applies to other crewed systems).

Stressors: Time to perform.

Notes: Model deals only with crew size as independent variable. Study of sleep loss effects is a longer term objective.

Schwartz, Shepard. (1968). Tank Crew Effectiveness in Relation to the Supervisory Behavior of the Tank Commander. (Technical Report 68-12). George Washington University.

Task: Tank preparation, tactical maneuvers and target engagement.

Stressors: None.

Notes: May be of interest in further understanding tank operations.

Scott, T.D. (1984). How to Evaluate Unit Performance. ARI Presidio of Monterey Field Unit.

Scribner, B.L., Smith, A.D., Baldwin, R.H., and Phillips, R.L. (1986). Are Smart Tankers Better? AFQT and Military Productivity. Armed Forces and Society, 12(2).

Seminara, J.L. and Shavelson, R.J. Effectiveness of space crew performance subsequent to sudden sleep arousal. Aerospace Medicine, 40, 723-727.

Task: Response time/monitoring alarm display, control panel settings, pressure suit donning.
Stressors: Sudden arousal from sleep during simulated 5-day lunar mission.
Notes: All RTs were slower following sudden arousal. Symptoms of drowsiness persisted for 9-12 minutes after alarm.

Shapiro, Y., Pandolf, K., Avellini, B., Pimental, N., and Goldman, R. (1980). Physiological responses of men and women to humid and dry heat. J. Appl. Physiol., 49(1), 1-8.

Shirom, A. (1979). On Some Correlates of Combat Performance. Administrative Science Quarterly, 21.

Sidowski, Joseph B. (Ed.) Behavior Research Methods, Instruments, & Computers. Journal of the Psychonomic Society, Inc., 17(1).

Notes: See various relevant articles in this document.

Siegel, A.I., Wolf, J.J., and Schorn, A.M. (1981). Human Performance in Continuous Operations: Description of a Simulation Model and User's Manual for Evaluation of Performance Degradation. (ARI Technical Report 505). Alexandria, VA: US Army Research Institute for the Behavioral and Social Sciences.

Task: Most critical tasks performed by mechanized infantry.
Stressors: Extended time in battle, night operations (low light), terrain, limits on sleep, enemy/friendly ratio.
Notes: This volume contains no technical information. See Vol. III, Technical Supplement. No primary data except model outputs.

Siegel, Arthur I., Leahy, Wm. Rick, and Wolf, J. Jay. (1978). Human Performance Tradeoff Curves for Use in the Design of Naval Systems. Wayne, PA: Applied Psychological Services.

Stressors: Hours worked, work load.
Notes: Purports to present tradeoff curves for various variables including hours worked and maximum stress. Based on model outputs.

Siegel, Arthur I., Pfeiffer, Mark G., Kopstein, Felix F., and Wilson, Lawrence G. (APS); Ozkaptan, Halim (ARI). (1979). Human Performance in Continuous Operations: Volume I. Human Performance Guidelines. U.S. Army Research Institute for the Behavioral and Social Sciences, Research Product 80-4a. (Full Synopsis in Appendix A).

Siegel, Arthur I., Pfeiffer, Mark G., Kopstein, Felix, Wolf, J. Jay, and Ozkaptan, Halim. (1980). Human Performance in Continuous Operations. Volume III. Technical Documentation. Wayne, PA: Applied Psychological Services Inc. (Full synopsis in Appendix A).

Siegel, Arthur I., Wolf, J. Jay, and Lautman, Martin R. (1974). A Model for Predicting Integrated Man-Machine System Reliability: Model Logic and Description. Wayne, PA: Applied Psychological Services.

Task: Various - not described.
Stressors: Hours since last sleep, physical effort required by tasks, hours available for recovery.
Notes: Primary data: none except as pertains to model. Fatigue function based on Kleitman (1963); tie to performance seems vague.

Simonov, P.V., Flolov, M.V., Evtushenko, V.F., and Sviridov, E.P. (1977, September). Effect of emotional stress on recognition of visual patterns. Aviation, Space and Environmental Medicine. 856-858.

Task: Perception of signal and non-signal dot patterns, each exposed for 2 seconds.
Stressors: Anticipation of parachute jump.
Notes: Relates to fear stress. Increase in perceptual errors as jump time approaches.

Simons, David G., Prather, Wealey, and Coombs, Franklin. (1965). The personalized telemetry medical monitoring and performance data-gathering system for the 1962 SAM-MATS fatigue study. Brooks Air Force Base, TX: USAF School of Aerospace Medicine.

Task: Flying aircraft simulator.
Stressors: 24 hour flight.
Notes: Report contains mostly a description of the instrumentation - no performance data.

Snook, S. (1971). The effects of age and physique on continuous-work capacity. Human Factors, 13(5), 467-479.

Snook, S., and Ciriello, V. (1974, November). The effects of heat stress on manual handling tasks. Am. Ind. Hyg. Assoc. J., 33, 681-685. (Abbreviated Synopsis in Appendix B).

Snook, S. and Irvine, C. (1967). Maximum acceptable weight of lift. Am. Ind. Hyg. Assoc. J., 28, 322-329.

Stressors: Continuous performance of physical tasks. Tote box height and weight varied; lifting frequency determined by subjects.

Tasks: Arm and leg lift tasks.

Results: Mean heart rate should not exceed 112 beats/min for leg tasks and 99 beats/min for arm tasks. Study served as a validation for psychophysical technique.

Snook, S. and Irvine, C. (1968). Maximum frequency of lift acceptable to male industrial workers. Am. Ind. Hyg. Assoc. J., 29, 531-536. (Abbreviated Synopsis in Appendix B).

Snook, Stover H., and Irvine, Charles H. (1969). Psychophysical Studies of Physiological Fatigue Criteria. Human Factors, 11(3), 291-300.

Task: Box lifting, shoe making.

Stressors: Work as hard as you can without becoming tired.

Notes: Primarily a physiological study with limited work periods.

- Soule, R., and Goldman, R. (1969). Energy cost of loads carried on the head, hands, or feet. Journal of Applied Physiology, 27(5), 587-690. (Abbreviated Synopsis in Appendix B).
- Soule, R., and Goldman, R. (1973). Pacing of intermittent work during 31 hours. Medicine and Science in Sports, 5(2), 128-131. (Full Synopsis in Appendix A).
- Soule, R., Pandolf, K., and Goldman, R. (1978a). Energy expenditure of heavy load carriage. Ergonomics, 21(5), 373-381. (Abbreviated Synopsis in Appendix B).
- Soule, R., Pandolf, K., and Goldman, R. (1978b). Voluntary march rate as a measure of work output in the heat. Ergonomics, 21(6), 455-462. (Full Synopsis in Appendix A).
- Spencer, M.B. (1987). The influence of irregularity of rest and activity on performance: a model based on time since sleep and time of day. Ergonomics, 30(9), 1275-1285.
- Stern, J.A. (1970). The Effect of Fatigue on Visual Search Activities. (Final Report Contract No. DA 49193MD2715). St. Louis, MO: Washington Univ.
- Sternberg, Jack J., and Hardy, Guthrie D., Jr. (1962). Survey of Human Factors in Armored Vehicles Operation. Washington, DC: Army Personnel Research Office.
- Task: Operate tanks and other armored vehicles for extended periods.
- Stressors: Heat, noise, vibration, bouncing, cold, confinement, isolation, sensory deprivation, danger.
- Notes: Though out of date provides good overview of stressors likely to affect tank crew performance. No data. Essentially a plan for further research.
- Stokes, J.W., Banderet, L.E., Francesconi, R.P., Cymerman, A., and Sampson, J.B. (1975). The Field Artillery Fire Direction Center as a Laboratory and Field Stress-performance Model. In: AGARD Conference Proceedings No. 180 on The Role of the Clinical Laboratory in Aerospace Medicine. (Abbreviated Synopsis in Appendix B).
- Storm, W.F., & Gray, S.F. (1978). Minuteman missile crew fatigue and 24-hour alerts. (Aerospace Medical Division AFSC, Report SAM-TR-78-19). Brooks Air Force Base, Texas: USAF School of Aerospace Medicine.
- Task: Minuteman crew tasks - not described. No performance measures.
- Stressors: 24 hr on-duty periods, catching sleep when can. Average: 5.9 hrs sleep.

Notes: Authors conclude moderate fatigue & physiologic cost present at end of 24 hrs. They state that this was not severe enough to cause decrement in crew effectiveness. There were no performance measures.

Storm, William F. (1983). Aircrew fatigue during extended transport, tactical and command post operations. In: AGARD Conference Proceedings No. 338. Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Flying various aircraft missions; airborne command-post operations.

Stressors: Various sustained missions, up to 30 hrs in duration.

Notes: All aircrewmen received more sleep than infantry or armor personnel are likely to get. Performance on the 30 hr command post mission was not suggestive of compromise although severe levels of fatigue were reported at end of mission (no performance data).

Storm, William F. (1980). E-4B Crew Fatigue Associated with 30-Hour IOT&E Mission. Brooks AFB, TX: School of Aerospace Medicine.

Task: No performance measures.

Stressors: 30 hrs continuous flying and C&C operations.

Notes: Author concludes crew was effective for 30 hrs based on subjective ratings and physiological measures. However, extreme fatigue was evidenced inadvertently after conclusion of the mission. No performance measures.

Swank, R.L. (1949). Combat Exhaustion: A Descriptive and Statistical Analysis of Causes, Symptoms and Signs. J. Nerv. Ment. Dis., 109, 475-508.

Task: N/A - A review of combat exhaustion cases in WWII.

Stressors: Prolonged, severe combat.

Notes: Relevance to our concerns only if allowance is to be made for loss of personnel due to combat exhaustion as consequence of high casualty rates with which it is associated. Swank postulates the interesting view that emotional tension resulting from a requirement for sustained, complete alertness is a more fundamental cause of combat exhaustion than fear of death or mutilation.

Symonds, Charles P., and Williams, Denis J. (1979). Clinical and statistical study of neurosis precipitated by flying duties. In: Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1943 report).

Symonds, Charles P., and Williams, Denis J. (1979). The psychological aspects of air sickness. In: Aircrew Stress in Wartime Operations. Papers from the Flying Personnel Research Committee of the Ministry of Defense. London: Academic Press. (Based on 1944 report).

Taub, J.M. & Berger, R.J. (1973). Performance and mood following variations in the length and timing of sleep. Psychophysiology, 10, 559-570.

Task: Addition (Experimental-paced), vigilance (auditory).
Stressors: Shifts from normal time of sleep, sleep deprivation (5 hrs allowed).
Notes: Sleep loss minimal.

Taub, J.M. and Berger, R.J. (1974). Acute shifts in the sleep-wakefulness cycle: Effects on performance and mood. Psychosomatic Medicine, 36, 164-173.

Tebbs, R.B. (1972). Post-awakening visualization performance as a function of anxiety level, REM or NREM sleep, and time of night. (Report No. TR-72-005). U.S. Air Force Academy, CO: Sailer Research Lab.

Technical Cooperation Program, Subcommittee on Non-Atomic Military Research and Development. (1974). Human Performance and Military Capability in Continuous Operations. (Note: Distribution limited to U.S. Gov't agencies only).

Teichner, W.H., and Olson, D.E. (1971). A preliminary theory of the effects of task and environmental factors on human performance. Human Factors, 13(4), 295-344.

Tepas, Donald I. (1984). Some relationships between behavioral and physiological measures during a 48-hour period of harassment. Honeywell.

Task: Reaction time, visual discrimination, time estimation.
Stressors: High intensity auditory stimuli.
Notes: No results presented. Much of copy received is illegible.

Terry, R.A., Kern, F.J., Nickel, J.A., and Palmer, J.D. (1984). Adaptive Processes used in effects modeling. Univ. of Oklahoma.

Task: N/A - concerns an attempt to model effects of non-nuclear weapons.
Stressors: Enemy bombing.
Notes: Possibly of use to modelers.

Tharp, V.K. (1978). Sleep loss and stages of information processing. Waking and Sleeping, 2, 29-33 and NHRC Report No. 77-43. San Diego, CA.

Task: Visual reaction time, with different levels of stimulus discriminability, compatibility, uncertainty.
Stressors: One night's sleep deprivation.
Notes: One night's sleep loss produced lapses in performance and a slowing of response selection process.

Thompson, Henry I. (1983). Sleep loss and its effect in combat.
Military Review, 14-22.

Task: Combat effectiveness generally. This is an essay.

Stressors: Sleep loss.

Notes: Useful in that reflects some thinking at Army Command Staff College, Ft. Leavenworth. Some useful description of current Soviet doctrine for continuous operations.
(Suggestion that Ranger School might be good source of observation.)

Thorne, D.R., Genser, S.G., Singe, H.C., & Hegge, F.W. (1983). Plumbing human performance limits during 72 hours of high task load.
Proceedings of the 24th Defence Research Group Seminar on the Human as a Limiting Element in Military Systems. Toronto, Canada: NATO Defence Res. Grp. (Full Synopsis in Appendix A).

Toomepuu Juri (1981). Soldier Capability - Army Combat Effectiveness (SCACE). Volume II. Selected Bibliography. Fort Benjamin Harrison, IN: Arm. Soldier Support Center.

Torre, J/P. and Kramer, R.R. (1966). The Effects of Stress on the Performance of Rifleman. (Tech Memo 5-66). Aberdeen Proving Ground, Maryland: Human Engineering Laboratories. (Abbreviated Synopsis in Appendix B).

Trites, D.K., and Sells, S.B. (1957). Combat Performance: Measurement and Prediction. Journal of Applied Psychology, 41(2).

Troxler, Raymond (Ed.). (1975). The Role of the Clinical Laboratory in Aerospace Medicine. Conference Proceedings, No. 180.

Trumbull, R. (1966). Diurnal cycles and work-rest scheduling in unusual environments. Human Factors, 8, 385-398.

Tsanava, N. and Maskov, S. (1971). A model of fatigue. Ergonomics, 14(1), 11-16.

Task: None.

Stressors: None.

Notes: Presents a model of biochemical and physiochemical fatigue.
No data.

Tyhurst, J.S. (1950). Behavior Under Stress. Paper No. 19. Ottawa, Canada: Defense Research Board.

Task: N/A (Adaptive response to disasters).

Stressors: Community disasters, (e.g., fires, floods).

Notes: A discussion paper on methods of field study with people who are victims of natural disasters.

Tziner, Aharon, and Edan, Dov. (1985). Effects of tank crew composition on crew performance: Does the whole equal the sum of its parts?
Journal of Applied Psychology, 70(1), 85-93.

U.S. Army. (1968). Catalog of Army War Games and Models. Washington, DC: Deputy Chief of Staff for Military Operations.

U.S. Army. ARTEP 17-55 (Armor): Excerpts. U.S. Army.

U.S. Army. MI Tank Technical Manual, TM 9-2350-264-10-2. HQ Dept. of Army.

U.S. Army. (1987). Continuous Operations Study (CONOPS) Final Report. Fort Leavenworth, KS: Combined Arms Combat Development Activity, Force Design Directorate.

U.S. Army. (1969). Infantry Rifle Unit Study Phase IIB-X (IRUS 70-75). Extended Duration Field Experiment (Final Report). Volume II. Technical Supplement. Fort Ord, CA: Combat Developments Experimentation Command.

Notes: Data not relevant to fatigue.

U.S. Army. Management of Stress in Army Operations. Field Manual 26-2. Fort Benjamin Harrison, IN: United States Army Soldier Support Center.

Task: Manage stress of soldiers in combat environment.

Stressors: Fatigue, mental stress, low light levels, NBC warfare, isolation, day/night rhythms, etc.

Notes: Handbook on stress management. Probably based on Siegel's work (see synopses).

U.S. Army TRASANA. (1985). TRASANA Analysis in support of the management of sleep and stress in continuous operations (MOSSICO) study. (Distribution of report is limited). US Army TRADOC Systems Analysis Activity. (Abbreviated Synopsis in Appendix B).

U.S. General Accounting Office. (1936 July). National Training Center's Potential Has Not Been Realized. National Security and International Affairs Division. Report to the Secretary of the Army. Washington, DC.

Ursin, H., Grahnsledt, S., and Hansen, I., Myhre, K., Opstad, P.K., Walther, B. and Anderson, H. (1983). Attention, Performance and Sustained Activation in Military Air Traffic Controllers. In: AGARD Conference Proceedings No. 338. Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Ground-controlled interception exercise involving two fighter aircraft.

Stressors: 45 to 60 minutes of continuous control performance.

Notes: The concern of this study was more with measurable stress response than with fatigue.

Van Nostrand, Sally J. (1986). Model Effectiveness as a Function of Personnel [ME = f(PER)]. Bethesda, MD: US Army Concepts Analysis Agency. (Abbreviated Synopsis in Appendix B).

Van Nostrand, Sally J., and Alderman, Irving N. (1966). Human Parameters in Theater-Level Combat Models. U.S. Army Concepts Analysis Agency. Bethesda, Maryland.

Task: Combat generally.

Stressors: Lower aptitude personnel, sustained operations, heat.

Notes: MORS symposium paper promoting development and use of per-
gorithms in combat models. Not as complete as Van Nostrand,
1986.

Vanderveen, Bart. (1984). World Directory of Modern Military Vehicles.
Argo Publishing Co.

Wagner, M., and Kunz, E. (1986). Development of a soldier load assess-
ment methodology. Andover, MA: Dynamics Research Corporation.
(Full Synopsis in Appendix A).

Wallace, J.R. (1982). The Gideon Criterion: The Effects of Selection
Criteria on Soldier Capabilities and Battle Results. Fort Sheridan,
IL: U.S. Army Recruiting Command, Research Studies and Evaluation
Division.

Warnick, W.W., Kubala, A.L., Mahey, J.L., and Ton, W.H. (1979). Study
of Psychological (and associated physiological) Effects on a Tank
Crew Resulting from Being Buttoned Up. ARI Research Problem Review
76-13 USARI.

Task: All tank crew tasks (not specifically studied).

Stressors: Continuous operations, confinement to buttoned up tank.

Notes: Despite the title, authors present no data on effects of
buttoning up, but simply speculate on what they might be.
They conclude, simply from a literature review that tank
crews can function continuously in the open hatch mode for
48 hrs with no degradation in performance. This is based on
Ainsworth & Bishop (see synopsis and critique of that
study).

Warren, N., & Clark, B. (1937). Blocking in mental and motor tasks
during a 65-hour vigil. J. Exp Psychol., 21, 97-105.

Task: Alternate addition/subtraction, color naming, tapping.

Stressors: 65 hrs without sleep.

Notes: Mental blocking is well documented. Few subjects. Tests
not frequent or long enough to show performance decrements.

Washburns, N.E. (1958). Evaluation of Thirteen Reports Prepared by
Psychological Research Associates, Inc. (CORG-A-76). Ft. Belvoir,
VA: Combat Operations Research Group.

Task: Estimate dangerousness from cues to enemy fire.

Stressors: Different kinds of small arms fire.

Notes: First systematic experimental studies of psychological
effects of various kinds of small arms fire. Appendix V
contains synopses of interest.

Webb, W.B. and Agnew, H.W. (1973). Effects on performance of high and low energy-expenditure during sleep deprivation. Perceptual and Motor Skills, 37, 511-514.

Task: Word memory, addition, vigilance (auditory), plus seven (speed of self paced mental addition).

Stressors: 2 nights sleep deprivation, peddaling exercise bicycle with 2.5Kg load.

Notes: No differential effects of physical exercise but this lasted only 15 minutes. Sleep loss had the usual negative effects on additions and vigilance.

Webb, W.B., & Agnew, H.W., Jr. (1974). The effects of a chronic limitation of sleep length. Psychophysiology, 11, 265-274.

Task: Vigilance (auditory), addition, word memory, grip strength.

Stressors: Sleep limited to 5 1/2 hrs for 50 days.

Notes: Authors conclude that chronic sleep loss of 2 1/2 hrs does not have major behavioral consequences. However, their testing times were very short (30 min) and were administered only once a day, in AM.

Webb, Wilse, B. (1985). Experiments of extended performance: repetition, age, and limited sleep periods. Psychonomic Society, Inc. In Behavior Research Methods, Instruments & Computers, 17(1). (Abbreviated Synopsis in Appendix B).

Wedderburn, Alexander A.I. (1987). Sleeping on the job: the use of anecdotes for recording rare but serious events. Ergonomics, 30(9), 1229-1233.

Wegmann, and Klein. (1983). Circadian Rhythms and Sustained Operations. In: AGARD Conference Proceedings No. 338. Sustained Intensive Air Operations: Physiological and Performance Aspects.

Task: Not applicable - general discourse on effects of circadian rhythms on performance.

Stressors: Sustained operations.

Notes: Discusses other factors (task variables, personality, motivation, physical activity) that influence circadian effects.

Weitz, Joseph. (1966). Stress. Institute for Defense Analysis, Research paper P-251.

Weitzman, Donald O. (1979). A survey of some human factors problems in night operations. U.S. Army Institute for the Behavioral and Social Sciences.

West, V., and Parker, J.F. Jr. (1975). A Review of Recent Literature: Measurement and Prediction of Operational Fatigue. Falls Church, VA: Biotechnology (AD A008 403).

Task: Non-specific.

Stressors: Long-term operations.

Notes: Review of fatigue concept & corollary variables. Annotated references. No particularly new insights.

Wherry, R.J., and Curran, P.M. (1965). A Study of Some Determiners of Psychological Stress. Pensacola, Florida: U.S. Naval School of Aviation Medicine. (Abbreviated Synopsis in Appendix B).

Wilkinson, R.F. (1958). The effect of sleep loss on performance. (Report No. 323). Cambridge, England: Applied Psychology Research Unit, Medical Research Council, pg. 36. (Abbreviated Synopsis in Appendix B).

Wilkinson, R.T. (1960). The effects of lack of sleep on visual watch-keeping. Quarterly Journal of Experimental Psychology, 12, 35-40. (Abbreviated Synopsis in Appendix B).

Wilkinson, R.T. (1961). Interaction of lack of sleep with knowledge of results, repeated testing, and individual differences. J. Exp. Psychol., 62, 263-271.

Task: 5-choice serial reaction.

Stressors: 30 hrs without sleep.

Notes: Feedback and knowledge of results greatly reduced adverse performance effects. Adverse effects increased over 6 week period of testing, probably because of reduced novelty of both test and stress condition. The same men showed the most performance impairment in 3 independent assessments.

Wilkinson, Robert T. (1963). Aftereffect of Sleep Deprivation. J. Experimental Psychology, 66, 439-442.

Task: Vigilance (visual), 5-choice serial RT.

Stressors: 34 hours without sleep on the 2nd night previous to the watch.

Notes: Aftereffect was greatest in the morning; subjects traded speed for accuracy.

Wilkinson, R.T. (1964). Effects of up to 60 Hours' Sleep Deprivation on Different Types of Work. Ergonomics, 7.

Task: Serial choice RT, vigilance (visual), card sorting, rote learning, various games.

Stressors: Up to 60 hrs awake, 4 1/2 hrs testing - 1 1/2 hrs resting (no sleep) in a repeated cycle.

Notes: Concludes that task interest and task complexity greatly affect amount of performance degradation.

Wilkinson, R.T. (1965). Sleep Deprivation. In O.G. Edholm and A. Becharach (Eds.), The Physiology of Human Survival. New York: Academic Press, 399-430.

Wilkinson, R.T. (1969a). Sleep Deprivation: Performance Tests for Partial and Selective Sleep Deprivation. Progress in Clinical Psychology, 2, 28-43.

Task: Choice reaction time, vigilance.

Stressors: Sleep deprivation.

Notes: Emphasizes importance of performance tests being more than a few minutes in length if effects of sleep deprivation are to be shown.

Wilkinson, R.T. (1969b). Some factors influencing the effect of environmental stressors upon performance. Psychological Bulletin, 72, 260-272.

Wilkinson, R.T. (1969c). Loss of Sleep. Proceedings of the Royal Society of Medicine, 62, 901-908.

Task: Vigilance, calculation of sums.

Stressors: Up to total loss of sleep on one or two nights. Continuous work.

Notes: When sleep reduced to 2 hrs night or 5 hrs on 2 successive nights, performance efficiency falls significantly. 100 hrs of sleep deprivation commonly produces psychotic symptoms, paranoia & delusions. This, then is some kind of upper limit.

Wilkinson, R.T. (1972). One Stress on Top of Another. New Society, 72-75.

Task: 5-choice serial RT.

Stressors: Sleep deprivation (30 hrs) low incentive (no knowledge of results), noise, alcohol.

Notes: One of few articles on stressor interactions.

Wilkinson, R.T., and Stretton, M. (1971). Performance after awakening at different times of night. Psychonomic Science, 23, 283-285.

Wilkinson, R.T., Edwards, R.S., and Harris, E. (1966). Performance Following a Night of Reduced Sleep. Psychonomic Science, 5, 471-472.

Task: Vigilance (auditory), addition (speed & errors).

Stressors: 2 sleepless working days, preceded by 0, 1, 2, 3, 5, or 7 1/2 hrs sleep the night before.

Notes: Less than 5 hrs sleep on a single night impaired vigilance; less than 3 hrs impaired calculation.

Williams, H.L., Gieseeking, C.F., and Lubin, A. (1966). Some effects of sleep loss on memory. Percept. Motor Skills, 23, 1287-1293. (Abbreviated synopsis in Appendix B).

Williams, H.L., Lubin, A., and Goodnow, J.J. (1959). Impaired performance with acute sleep loss. Psychological Monographs: General and Applied, 73.

Task: Reaction time, adding, communication, concept attainment, vigilance, information learning.

Stressors: Sleep loss; 74-98 hours.

Notes: Very comprehensive study.

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

Task: Addition, with various speed loads.

Stressors: 64 hrs without sleep.

Notes: Impairment was a multiplicative function of speed load and sleep loss. Very short testing times.

Williges, Robert C. (1987). The use of Models in Human-Computer Interface Design. Ergonomics, 30(3), 491-502.

Woodward, Donald P. and Nelson, Paul D. (1974). A User Oriented Review of the Literature on the Effects of Sleep Loss, Work Rest Schedules, and Recovery on Performance. Arlington, VA: Office of Naval Research. (Full Synopsis in Appendix A).

Wyndham, C., Strydom, N., Morrison, J., du Toit, F., and Kraan, J. (1954, May). Responses of unacclimatized men under stress of heat and work. J. Appl. Physiol., 6, 681-686.

Yarnold, K. (1951). Fear in Battle. Dunlap & Associates., Inc.

Zimolong, Bernhard, Nof, Shimon Y., Eberts, Ray E., and Salvendy, Gavriel. (1987). On the Limits of Expert Systems and Engineering Models in Process Control. Behaviour and Information Technology, 6(1), 15-36.