SPECIAL SECTION

Methodological Approaches to the Study of Sustained Work/Sustained Operations

Introduction

GERALD P. KRUEGER

Walter Reed Army Institute of Research, Washington, DC

and

CARL E. ENGLUND

Naval Health Research Center, San Diego, California

In this issue, we describe diverse methodologies used in sustained work/sustained operations (SUSOPS) laboratory and field research. Communication among contemporary sustained operations researchers has been enhanced recently by the publications appearing in two issues of this journal (February and December 1985), the two Toronto meetings from which most of these manuscripts were derived, an annotated bibliography containing almost 400 references (Krueger, Cardenas-Ortiz, & Loveless, 1985), and the formation of a United States Department of Defense Human Factors Engineering SUSOPS Technical Advisory Subgroup. The timing for this cooperative effort is appropriate for several reasons: (1) the methodologies used in studies of the type described here

are maturing rapidly; (2) industrial and, in particular, military concerns for research-based predictions and recommendations on sustained operations applications have intensified; and (3) round-the-clock experiments and field tests involving collection of data on large numbers of participants necessitate that we learn from one another. To be effective and efficient, collaborative research programs are necessary.

The first special section devoted to the study of sustained work/sustained operations (see Englund & Krueger, 1985) delineated two types of continuous operations: (1) *extended operations* and (2) *sustained operations*.¹ The study of worker performance in extended/sustained operations requires eclectic methodologies drawn generally from research on work-rest cycles (e.g., Alluisi & Morgan, 1982), shift-work systems (e.g., Colquhoun & Rutenfranz, 1980; Tepas, 1979; Tepas et al., 1985), and sleep deprivation (e.g., Webb, 1968, 1985). Methodologies are evolving, and research paradigms are focusing on the identification of the major independent variables of interest: prior rest quantity and quality, types of work and tasks, amount of workload, times of day of performance, work/rest cycles, naps, circadian rhythms, diet, physical fitness, environmental conditions, and pharmacological intervention to sustain or enhance performance.

An important component of many SUSOPS experiments is the study of performance as a function of time of day, over a period of several days. Researchers often design studies to measure continuous performance on simulated "real-life" tasks. In other studies, researchers measure periodic task performance, using batteries of brief standardized laboratory tasks designed to evaluate a range of psychological functions. Examples of general classes of dependent measures are: accuracy scores, reaction times, evoked and event-related potentials in sensory, percep-

This is the second special section in *Behavior Research Methods, Instruments, & Computers* dedicated to methodological approaches for the study of sustained work/operations (SUSOPS). As in the first section (February 1985), several manuscripts were presented previously at a workshop and a symposium held August 1984, in Toronto, Canada. The workshop on "Sustained Operations Research" was hosted at the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) on August 23, 1984. A symposium on "Sustaining Work Hours Without Decrements in Productivity" was given on August 25, 1984 at the 92nd annual meeting of the American Psychological Association (APA). Both meetings were organized and cochaired by Dr. Carl E. Englund and Dr. Gerald P. Krueger.

The DCIEM workshop and the APA symposium served as the nucleus for the formation of the United States Department of Defense Human Factors Engineering Technical Advisory Subgroup (SubTAG) on Sustained-Continuous Operations. The remaining articles in this special section were developed as a result of the SubTAG's formation meeting, chaired by G. P. Krueger in San Antonio, Texas, in May 1985.

G. P. Krueger's mailing address is: Division of Neuropsychiatry, Walter Reed Army Institute of Research, Washington, DC 20307-5100. C. E. Englund's mailing address is: Environmental Physiology Department, Naval Health Research Center, P.O. Box 85122, San Diego, CA 92138-9174.

tual, psychomotor, vigilance, memory, and cognitive tasks; physical, psychological, physiological, electrophysiological, and biochemical measures; histories, questionnaires, self-administered scales of subjective states (mood, fatigue, beliefs, symptoms), and performance ratings.

Since several independent variables almost always interact, sustained operations experiments are usually strengthened through multivariate designs. Measuring several dependent variables in the same study serves to more accurately describe the SUSOPS performance profile and the results tend to have greater generality and applicability.

The study of sustained, extended, and continuous operations not only involves many classical behavioral and psychophysiological techniques but, more importantly, involves sets of rather unique experimental considerations and circumstances. Sustained operations research protocols differ significantly from most other experimental psychology studies, primarily because they require long, continuous hours of performance by test subjects. Subjects in sustained operations studies must participate for many days without breaks, and are frequently isolated from normal time references or personal activities. Motivational variables are especially important. Indeed, for a myriad of physical, physiological, or psychological reasons (e.g., fatigue, exhaustion at the tasks, or simply lack of will to continue), subjects occasionally fail to complete all assigned tasks, change response strategies, make decisions to complete tasks inaccurately (or at least appear to), and in some cases fail to complete the experiment. Frequent topics of investigation include boredom, changes in mood, performance lapses, and microsleep.

Maintenance of subject interest over long periods of time is enhanced by exciting or job-related challenging tasks with feedback; thus, such tasks are frequently embedded in operational work scenarios (see, Angus & Heslegrave, 1985; Graham, Cook, Cohen, Phelps, & Gerkovich, 1985; Heslegrave & Angus, 1985; Krueger, Armstrong, & Cisco, 1985) so that subjects relate to them as part of their "normal jobs." Under these conditions, individual differences become more manifest and task performance variance increases. Individuals should be profiled for their differences along physiological, psychological, cognitive, psychomotor, perceptual, and performance variables. For example, so-called "daytime people" or "larks" are asked to perform through the night and into the early morning hours that include known circadian lull periods. Night people, or "owls" must perform at all hours of the day.

Since participants in SUSOPS studies must relinquish their normal day-to-day routines, researchers must be cognizant of the effects of such displacement. For example, what are the effects of denying daily joggers their usual run and imposing on them essentially an interrupted, sedentary, continuous command and control environment for several days at a time? Knowing the fitness level of subjects who participate in physically demanding field studies is important (Englund, Ryman, Naitoh, & Hodg-

don, 1985; Pleban, Thomas, & Thompson, 1985), because fitness may relate to SUSOPS performance durability.

Subjects may be asked to restrict their diets and to sacrifice caffeine-laden morning coffee or soft drinks, alcohol, and tobacco (see, e.g., Rosa, Wheeler, Warm, & Colligan, 1985). Depending upon the circumstances, some participants eat and drink less as the test progresses, while some do just the opposite; thus, weight changes and dehydration become considerations, especially in demanding field tests. Monitoring of body temperature is important, not only for considerations of subject comfort and safety in tests with specialized equipment or clothing, but also because body temperature changes are important markers of individual biological and circadian profiles (Monk et al., 1985).

In addition to describing SUSOPS performance per se, investigators study possible solutions to applied problems. One such example is the purposeful introduction of naps, scheduled as short sleep periods in the context of a scenario lasting several days. Naps are studied for their intrinsic as well as enhancement potential (Dinges, Orne, & Orne, 1985; Haslam, 1985a; Naitoh, Englund, & Ryman, 1982). Unscheduled naps also are studied; after many hours or days of testing, and certainly in the face of progressive sleep deprivation, subjects take naps unscheduled by the experimenter (Krueger, Armstrong, & Cisco, 1985), and transient perceptual distortions and hallucinations are occasionally reported (Babkoff, Sing, Hegge, Thorne, & Genser, in preparation; Johnson & Naitoh, 1974; Mullaney, Fleck, Okudaira, & Kripke, 1985).

In SUSOPS studies, subjects experience more than the "standard stimulus presentation" common to many classical psychological performance studies. Frequently, it is group, team, or crew performance on tasks that must be studied. In shared group tasks, not all participants are exposed to the same sets of stimuli. Either subjects are responsible for the accomplishment of different components of the tasks, or their common workload is divided by group decision.

Some SUSOPS tasks and, therefore, experiments are machine-paced (e.g., Dinges & Powell, 1985; Dinges & Whitehouse, 1985; Graham et al., 1985; Mullaney et al., 1985; Webb, 1985), many are self-paced (Angus & Heslegrave, 1985; demanding duty cycles (e.g., Babkoff, Thorne, Sing, Genser, Taube, & Hegge, 1985; Englund et al., 1985; Heslegrave & Angus, 1985; Krueger, Armstrong, & Cisco, 1985).

In sustained operations research, it is not sufficient to select experimental tasks merely because they are known to be sensitive to sleep-deprivation effects. It is as important to identify those performances that do not degrade as it is to determine those that degrade as a function of "time on the job." The study of a process, rather than the study of single item tests or tasks, is therefore usually more important. Experimental tasks are selected for what they reveal about the practical, applied, and generalizable functions over days rather than for their psychomet-

ric history. Description and prediction rank higher as research objectives than do explanation and control.

Because absolute experimental control may not be possible, the need for new analytical procedures has become increasingly apparent. Examples of different analytical approaches are the various time-series analyses noted in this issue (e.g., Naitoh, Englund, & Ryman, 1985; Sing, Thorne, Hegge, & Babkoff, 1985). Protocols include repeated measures designs over extended periods of time; thus, researchers need to account for the variance in the data attributed to circadian and ultradian periodicity/cycles (Monk et al., 1985).

The complexity and interface requirements of instrumentation have increased. Combination laboratories consisting of physiological, biomedical, and experimental psychological configurations are typical. Electrocardiogram (EKG), electroencephalogram (EEG), electromyogram (EMG), and electrooculogram (EOG) recorders and evoked potential and topographic mapping systems are used in many lab studies. To obtain EKG, EEG, EMG, EOG, and body temperature measures, subjects in both lab and field studies are frequently "wired" with chest and scalp electrodes, rectal probes, telemetry devices, and other monitors. Microprocessors and minicomputers are used extensively in the administration of tests (e.g., Babkoff, Thorne, Genser, Sing, & Hegge, 1985; Mullaney et al., 1985; Rosa et al., 1985; Thorne, Genser, Sing, & Hegge, 1985; Webb, 1985); however, it is not uncommon to use paper-and-pencil tests (e.g., Morgan, Jacobson, Wilt, Krueger, Thorne, & Smith, 1985) and other methods when more modern equipment fails to meet the measurement needs in a given situation.

Laboratory SUSOPS studies often simulate "real-world" sustained operations settings (e.g., Angus & Heslegrave, 1985; Krueger, Armstrong, & Cisco, 1985; Stokes, Banderet, Francesconi, Cymerman, & Sampson, 1975). In some cases, lab-based methodology has been transported to the field (Kimball & Anderson, 1975; Lees, Stone, Jones, Kimball, & Anderson, 1979; Morgan et al., 1985; Pleban et al., 1985). Field studies require lightweight, portable, unobtrusive activity-monitoring devices (e.g., Mullaney, Kripke, & Messin, 1980; Redmond & Hegge, 1985), which can record levels of activity and amounts of sleep in natural uninterrupted settings.

Problems encountered in running SUSOPS studies are innumerable. Because these experiments run over long periods of time, research equipment may break down, or weather may affect planned field exercises. Redundancy of expensive equipment is required to protect against apparatus or instrumentation breakdown. Often, delays result while changing from one set of equipment to another. Storms and static discharges cause electrical problems that affect computerized equipment for scheduled test presentations and data-collection apparatus. In some studies, the continuous running of the clock or the passage of time for particular test subjects on the job is one of the main variables of interest; experimenters do not have the option of rerunning a data-collection session when such uncontrolled variables impact a study. One can-

not simply stop and redo many experimental runs. In most studies, it would be cost prohibitive to repeat the work, and in others, the situation being studied cannot be repeated. Thus occasional empty data cells sometimes cause problems during statistical analyses.

Collecting data continuously for days or weeks at a time, on multiple measures, from multiple subjects, can result in a database two to three orders of magnitude larger than many of our colleagues in other disciplines are accustomed to seeing. This greatly increases the labor, time, and cost of both data collection and data analysis. While no simple solution to this problem has emerged, it should be noted that much of current SUSOPS research would be impossible without today's inexpensive computers. Future research will require improved methods for automating the collection, encoding, and preprocessing of experimental data.

Military requests for research-based predictions and recommendations on sustained operations applications have intensified during the past several years. Military services around the globe have predicted the likelihood of sustained and continuous operations on battlefields. The military develops special case situations in which, for example, combatants are expected to work for extended periods of time while encapsulated in chemical warfare protective clothing, sometimes in excessively hot or cold environments; or while using electro-optical and night vision devices to detect and track targets, or piloting extended cargo flight missions over water, or controlling low-flying helicopters for many hours without adequate rest. Such complex work environments raise new psychological and physiological performance questions that the military and other organizations must address (e.g., Ernsting, 1983; Simpkin, 1983). Additionally, researchers must address the question of the efficacy of pharmacological means, such as hypnotics, to assist in the management of sleep during irregular work schedules or the use of stimulants to sustain and enhance performance (e.g., Baird & Nicholson, 1983; Nicholson, 1983).

Many new variables are being identified. Most of these must be evaluated in field studies using large numbers of participants in situations in which the variables are inherently more difficult to control. Perhaps one of the most frustrating lessons for sustained operations researchers is that much of what has been done in the laboratory does not easily extrapolate to the large field study. Adapting proven lab-based methodologies to the more complicated field study is a challenge. All of the difficulties of setting up good, well-controlled laboratory studies intensify with field studies. Considerations of suitable performance-measurement tasks, selection and reliability of instrumentation, scheduling, equipment maintenance, weather, number of participants moving about in the macroenvironment, and many uncontrolled variables are all amplified in a field study that runs for 24 h per day over many days.

As Morgan and Pitts (1985) indicated, much of the initial effort in this area of research has been devoted to developing suitable methodologies for assessing human performance over prolonged periods of time. In part, the two

special sections of this journal devoted to methodological issues of sustained operations research are an attempt to present the state of the art on the subject.

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NOTE

1. Extended operations: Jobs or tasks that proceed continuously with only a short break or breaks, but that operate within a typical shift system for periods longer than a normal duty day. The worker knows he/she will be relieved or able to rest.

Sustained operations: Planned or unplanned, goal-oriented, nonstop continuous performance/operations without rest or sleep, in which the worker is expected to keep going as long as he/she can (Englund & Krueger, 1985).