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Sustained Work, Fatigue, Sleep Loss and Performance: A Review of the Issues

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By

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The physiological and psychological stressors associated with sustained work, fatigue, and sleep loss affect worker performance. The review describes findings relating to sustained work stresses commonly found in our advancing technological world. Researchers report decrements in sustained performance as a function of fatigue, especially during and following one or more nights of complete sleep loss, or longer periods of reduced or fragmented sleep. Sleep loss appears to result in reduced reaction time, decreased vigilance, perceptual and cognitive distortions, and changes in affect. Sleep loss and workload interact with circadian rhythms in producing their effects. These interactions are a major source of stress in work situations requiring sustained work in continuous operations and have implications for theoretical models of sustained perceptual and cognitive functioning. This review highlights the research issues of 280+ members of a U. S. Department of Defense sponsored Human Factors Engineering international Technical Group on Sustained and Continuous Operations.

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Review Paper

Sustained work, fatigue, sleep loss and performance: a review of the issues

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The physiological and psychological stressors associated with sustained work, fatigue, and sleep loss affect worker performance. This review describes findings relating to sustained work stresses commonly found in our advancing technological world. Researchers report decrements in sustained performance as a function of fatigue, especially during and following one or more nights of complete sleep loss, or longer periods of reduced or fragmented sleep. Sleep loss appears to result in reduced reaction time, decreased vigilance, perceptual and cognitive distortions, and changes in affect. Sleep loss and workload interact with circadian rhythms in producing their effects. These interactions are a major source of stress in work situations requiring sustained work in continuous operations and have implications for theoretical models of sustained perceptual and cognitive functioning.

Keywords: Fatigue; Sleep deprivation; Sustained work; Continuous performance; Continuous operations; Circadian rhythms.

1. Introduction

Human productivity is often epitomized by work schedules that employ workers around-the-clock: such uninterrupted schedules of nonstop activity are known as 'continuous operations' (CONOPS). Individuals involved in CONOPS often work a regularly scheduled 'normal shift length' (7–12 h) and then are relieved by others while the overall operation continues. Workers later return to the job as scheduled and presumably after adequate rest and sleep. Examples of CONOPS range from chemical process and energy production plants through police, fire and rescue operations, transportation, communication, and food services, to operating worldwide investment marketing centres, and many others. Technological innovations, such as night vision systems for military forces, can serve to promote increased around-the-clock activity. CONOPS often imposes on workers psychological and physiological stresses that have a negative impact on productivity, accident, and absenteeism rates (Colquhoun and Rutenfranz 1980, Johnson *et al.* 1981, Alluisi and Morgan 1982, Folkard and Monk 1985, Tepas *et al.* 1985, Tepas and Monk 1987).

Many individuals work on shifts longer than 12 h, often performing at close to a nonstop rate for as long as they can. These unusually long work stints are referred to as 'sustained operations' (SUSOPS). Often they are not planned, but must be continued until a goal is reached. They generally last long enough for workers to experience fatigue and sleep loss. This often leads to reduced performance, efficiency and effectiveness. Examples of SUSOPS include: staffing hospitals during internship, performing lengthy emergency medical operations, long rescues, evacuations at disaster sites, fighting forest fires, military training missions, combat operations, aerospace missions, sailing in a storm and participating in endurance sport activities. In the more conventional CONOPS shiftwork setting, workers occasionally participate in bouts of SUSOPS during periods of 'overtime' work.

Often SUSOPS workers are asked to maintain acceptable levels of sustained performance, staving off fatigue and performance decrements. A number of factors associated with sustained work affect the psychological and physiological condition of workers and moderate job performance during SUSOPS. These are reviewed here.

1.1. *Characteristics of the job, work tasks*

1.1.1. *Continuousness of tasks*

The extent to which a job requires sustained effort affects performance. Some jobs require long hours of constant attention, prolonged uninterrupted activity, and/or stamina often in a monotonous or repetitive environment. Crosscountry truck driving and lengthy periods of monitoring radar are two examples of this. Other jobs involve periods of continuous work interspersed with markedly reduced activity, lulls, or even rest breaks. Piloting long-haul flights with sufficient crew, processing paperwork, and making computer entries are three examples of this. SUSOPS workers who continuously perform cognitive tasks for extended periods show predictable performance decrements. Angus and Heslegrave (1985) required subjects to do 54 h of continuous work simulating handling of message traffic and information processing. They found reaction time, logical reasoning, vigilance, encoding, and decoding declined after 18 h work in a stepwise manner, dropping over the next 6 h to 70% of baseline. Performance was stable at 70% for the next 18 h, declining over the next 6 h to 40% of baseline, and then remaining stable at 40%. Deterioration of mood and motivation, and increases in subjective reports of sleepiness and fatigue paralleled the decline in performance. Furthermore the greatest declines in performance over successive nights without sleep coincided with the trough of the circadian cycle (0300–0600 h). In another study, Mullaney *et al.* (1983, 1985), using a computerized test battery for 42 h, obtained similar results.

1.1.2. *Vigilance and attention*

Mackworth (1957) refers to vigilance, or monitoring tasks, as requiring a state of maximum physiological and psychological readiness to react. Vigilance characterizes an observer's ability to detect and respond to small stimulus changes that require direct attention to sources of stimulation for long, unbroken periods of time, such as watching a radar screen (Mackworth 1957, Davies and Parasuraman 1982). Although many jobs require continuous monitoring for two or more hours, the quality of sustained attention on such tasks wanes rapidly.

Observers become progressively less efficient at detecting either visual or auditory signals as vigilance time continues (Stroh 1971, Mackie 1977, Warm 1984). 'Vigilance decrement' is characterized by a drop in the number of correct detections and/or by a rise in response time to correct detections. Most studies suggest vigilance decrement can be expected as early as 20–35 min after initiation of a vigil, although this depends on factors like the background event rate, the sensory modality, and amplitude of critical signals. In addition, environmental stressors, such as heat, cold, noise, vibration and the state of alertness (fatigue level) of the observer can affect performance during prolonged periods of sustained attention.

There are many work situations in which failure to detect critical signals can be disastrous, for example, an anesthesiologist monitoring medical displays during surgery or an operator monitoring control panels at a nuclear power plant. Short monitoring stints of less than 4 h have been recommended (Warm 1984), but are not always practical for these jobs.

1.1.3. *Machine-paced versus worker-controlled tasks*

In machine-paced, or event-driven tasks, these factors control when a response is to be made. Reaction time and task duration are important in predicting machine-driven task performance. In contrast in a completely worker-controlled task, the worker determines when the item to be responded to appears, its duration, and the time within which the response must be made. Reaction time is thus less important in worker-controlled tasks, and task duration will be more variable. Examples of worker-controlled tasks include making telephone sales calls or entering information into computers.

Salvendy (1981) estimated that over 50 million workers perform predominately machine-paced tasks. Machine-pacing can provide consistent production rates, but the resulting performance demands may increase the stress on workers. In SUSOPS, performance differs as a function of the type of job pacing. Performance on machine-paced tasks is often affected by small amounts of sleep loss leading to errors of omission (Williams *et al.* 1959).

1.1.4. *Physical versus cognitive tasks*

Sustained intense physical effort can lead to muscle fatigue, and eventual failure to perform, just as sustained cognitive work can lead to general feelings of fatigue or weariness, and in the chronic extreme, to 'burn out'. The main effects of any associated sleep deprivation appear to be psychological rather than physiological (Haslam and Abraham 1987, Haslam 1982, Englund *et al.* 1985, Martin *et al.* 1986).

The main effect of sleep loss on physical capability is a slowing of the biological recovery process in response to muscular exercise and therefore there is a subsequent need for a slightly longer recuperative period (McMurray and Brown 1984).

Sleep loss also hastens the onset of, and increases the frequency of cognitive performance decrements, especially on attention demanding vigilance tasks during sustained work. Performance on cognitive tasks involving memory, learning, logical reasoning, arithmetic calculations, pattern recognition, complex verbal processing and decision making has been shown to be impaired by sleep loss to a measurable extent beyond that anticipated by the effects of sustained effort alone (Babkoff *et al.* 1985, Englund *et al.* 1985, Haslam and Abraham 1987). However, the degree to which performance is impaired by sleep loss does depend upon task variables such as duration, knowledge of results, difficulty of task, task pacing, proficiency level, task complexity, and memory requirements (Johnson 1982).

1.2. *Rhythmic variations in worker performance*

Workers exhibit various predictable physiological and behavioural rhythms, within a period of about a day, i.e., circadian rhythms. Alertness declines most as body temperature decreases to its lowest level from 0300–0600 h and to a lesser extent from 1600–1800 h (Minors and Waterhouse 1985, Monk *et al.* 1985).

For most people, night-work is a problem because it calls for an overriding of circadian variations and demands (Tepas and Monk 1987, Monk and Embrey 1981, Folkard and Monk 1979). This presents a paradox for workers expected to sustain performance around the clock.

Worker performance not only varies with time-of-day, but also interacts with work schedule and may result in different time-of-day effects for different tasks (Monk and Embrey 1981, Monk *et al.* 1983). The simple generalization that workplace performance is poorest in the early morning hours must therefore be qualified. Some work schedules may result in the best performance for one type of task in the early morning hours and yield the poorest performance for another type of task at the same time of day (Folkard and Monk 1979).

'Ultraradian rhythms', cyclical variations in efficiency and alertness having a period of less than 12 h are also seen in sustained work. Several authors have described ultraradian rhythms in terms of a commonly occurring 90-min cycle patterning, but usually in relation to biological processes such as sleep stage patterning, pupil dilation, duration of the spiral after-effect, and digestive functioning. The 90-min rhythm is common, but is often masked in data where it might be expected to appear (Lavie 1982, Hockey 1986).

By way of overview, it is worth noting that Trumbull (1966) has described 50 normal patterns of neuro-physiological and psychological rhythms within humans that have various degrees of influence upon their level of performance and ability to maintain performance.

1.3. *Weariness, tiredness and fatigue*

'Physical fatigue' may be thought of as the temporary loss of power to respond, induced in a sensory receptor or motor end organ by continued stimulation. It is the muscular tiredness one feels after sustained vigorous exercise, repeated lifting, or digging. Physiologists describe it as a decrease in physical performance (Simonson 1971, Simonson and Weiser 1976); but often it has a strong cognitive component (Hockey 1986). The decision that muscular work (e.g., pulling a dynamometer handle) is no longer possible can occur well before the physiological limit has been reached. Caldwell and Lyddan (1971) showed 'maximal pull' was greater if subjects expected longer rest pauses between trials.

'General fatigue', sometimes referred to as 'mental fatigue', is the subjective feeling of weariness which accompanies repeated performance of almost any nonphysical task. The lack of novel stimuli brings on feelings of monotony and boredom, accentuated by tiredness and drowsiness associated with sleep loss. Grandjean (1968) interprets this general fatigue as a consequence of reduced afferent impulses or reduced feedback from the cortex to the reticular activating system. Somewhat by contrast, Bartley (1965) viewed fatigue as a 'whole' symptom felt throughout the body, attributable to physiological changes in internal organs. Boredom can become apparent within minutes of the onset of a monotonous task (O'Hanlon 1981), but mental fatigue typically is a product of hours of continuous work.

Holding (1974) demonstrated, after 24–32 continuous hours on a multiple-performance battery, that fatigued subjects, who are given a choice of effort level and corresponding probability of success, are more likely to choose a strategy of low effort/low probability of success. Hockey (1986) suggests prolonged periods of cognitive overloading puts individuals into states where any further effort to meet task demands is aversive. This normally leads to shortcuts and inconsistent application of task-related behaviour. This, Hockey (1986) argues, amounts to a strategic change rather than a fundamental reduction in operating efficiency. However, sleep deprived subjects improve in their cognitive performance when they hear a nap soon will be permitted (Haslam 1985 a). Thus the notion of 'aversion to effort' may be central to the demonstration of both physical and mental fatigue. However, we often see fatigued workers suddenly stop their work, be it physical or cognitive, and vigorously participate in sporting activities, or computer games during 'break'.

Hockey (1986) also differentiates short-term fatigue effects from those of prolonged cognitive overloading, calling them 'phasic fatigue' which he says may represent fundamental changes in the level of system efficiency. Phasic fatigue can result from prolonged vigilance in which the worker occasionally exhibits an unusually long response time, misses signals, exhibits brief interruptions in performance (lapses in attention), makes more errors of choice, or, maintains accuracy, but sacrifices speed of performance and consequently accomplishes less work per unit time.

Since fatigue is predominately subjective, it is hard to quantify. Skill performance studies show, in addition to increased reports of 'feeling fatigued', workers also change their patterns of attention with prolonged work. As early as the 1940s, Bartlett (1942) noted fatigued pilots make larger control errors – though generally less often – and timing of coordinated movements and manoeuvres becomes less accurate, while instruments and actions attended to only occasionally are likely to be forgotten. Unrecognized and uncontrolled fatigue almost always gives rise to marked irritability. Similar more recent findings with helicopter pilots were reported by Lees *et al.* (1979) and Krueger *et al.* (1985 a).

1.4. *Work rest-breaks, work shifts and work/rest cycles*

Change *per se*, i.e., novel stimuli, plays a significant role in overcoming the effects of fatigue. Thus, work breaks or pauses, and split shifts are ways of overcoming acute fatigue effects.

1.4.1. *Work–rest breaks*

Although there are not many hard data to defend short rest breaks, there is limited evidence to support the assumptions that short breaks in 'machine-paced' jobs are beneficial in terms of alleviation of fatigue, that they do not reduce output even though less time is worked, and in some cases can lead to increased productivity and employee satisfaction (McCormick and Tiffin 1974, Alluisi and Morgan 1982). The benefits of rest pauses in most sedentary and light physical activities may derive more from subjective factors like relief of boredom. Where repetitive heavy physical activities such as lifting are involved, rest, or changes-of-activity can preclude muscle fatigue and cardiac strain (McCormick and Tiffin 1974).

Optimum schedules of rest pauses have not been determined for different kinds of work, workers, and conditions of work. With the present trend toward jobs that require more cognitive work, the issue of rest breaks deserves new examination. Janaro and Bechtold (1985) describe attempts to determine optimal rest break scheduling models for developing policies to minimize fatigue and optimize work output.

1.4.2. *Shift work schedules*

Alluisi and Morgan (1982) remind us that in 1890, blast furnaces kept men working 12 h per day, 7 days per week for 84-h workweeks. Later reductions in the length of the workweek resulted in decreases in accidents, absenteeism, and in some cases, increased productivity. However, it is clear that the effects of total work hours on human performance and productivity interact with many other factors. No single work schedule is likely to be optimum for all tasks or all industries.

If there are sufficient personnel to maintain continuous productivity, individual workers can follow alternating shiftwork schedules. Daily shifts may vary from 8 h of work followed by 16 h off duty, or 12 h on–12 h off to more continuous schedules alternating sequences of 4 h of work followed by 4 h off duty, or 4 h work with 2 h off duty (Chiles *et al.* 1968, Alluisi 1969). Depending on local custom, the nature of the work, and the type of workers (e.g., part vs. full-time), many alternative schedules permit CONOPS.

1.4.3. *Work/rest cycles: SUSOPS in small teams*

Continuous operations often means employing crews of 2–3 personnel, charged to perform 24-h per day. Although military operations are not always analogous to industrial shiftwork, some of the basic tenants are similar. Instead of going home at shift change, the soldier, sailor or airman scheduled to alternate with a team member on the job ('shiftworkers') usually rests or sleeps nearby, even in the crew compartment or workstation itself.

Operation of ships or submarines presents a variety of scheduling problems including those relating to work shifts, meals, sleep, and recreation. Kleitman and Jackson (1950) focused on sleep and body temperature in identifying the advantages of different ship-watch schedules, beginning with various alterations to 'standardized' rotating shifts of 4 h on and 8 h off duty. They concluded the closer ship-board schedules are to typical shore-based work–rest cycles the better the adaptation of body temperature to the activity cycle. Because performance was positively correlated with temperature, crew performance would be improved by following such schedules. Colquhoun *et al.* (1968 a, 1968 b, 1969) conducted naval-watch studies on alternating shifts to compare 3-person 8-h rotating shifts with 2-person 12-h shift schedules. Two-person shifts, because they were stabilized, exhibited higher mental task performance efficiency, better adaptation, and better maintenance of 24-h work.

In preparation for aerospace missions, Chiles *et al.* (1968) conducted a set of comprehensive and informative studies of rapidly alternating work–rest schedules. Subjects with work-to-rest ratios of 1 : 1 participated in one of four work–rest cycles for 4 continuous days: (*a*) alternating 2 h on duty and 2 h off; (*b*) 4 h on and 4 h off; (*c*) 6 h on and 6 h off; or (*d*) 8 h on and 8 h off. Regardless of the schedule, performance scores on vigilance, computational, target identification, and crew code-lock solving tasks improved throughout the 96 h. In a similar study of work–rest ratios of 2 : 1, subjects were scheduled 4-h on duty and 2-h off around the clock for 4 days; and for a ratio of 3 : 1, were scheduled 6-h on and 2-h off (Chiles *et al.* 1968). Both schedules gave clear evidence of circadian variations in all performance measures, but neither was significantly better than the other. Subjects preferred the 4–2 over the 6–2 schedule and the former averaged 5·5 h of sleep per 24-h period, whereas those on the 6–2 schedule averaged less than 4 h sleep.

Subsequently, in 15-day (360 h) and 30-day (720 h) confinement studies, employing 4–2 and 4–4 schedules respectively, those on the 4–4 schedule maintained consistently better levels of performance than those with the 4–2 schedule. When one 15-day group was shown psychophysiological and performance data of another group, and was told their goal was to prevent the appearance of circadian low points, they were able to do so, demonstrating benefits of feedback and motivation. Overall, Chiles *et al.* (1968) showed that: (1) subjects working 12 h per day on a 4–4 schedule can maintain generally higher levels of performance than subjects working 16 h per day on a 4–2 schedule; (2) some subjects can work 16 h per day on a 4–2 schedule with essentially no decrements over a period of at least 15 days; (3) when subjects are highly motivated, performance over a period of 30 days on a 4–4 schedule is indistinguishable from the levels maintained by subjects following a stabilized 8-h split-shift in a nonconfinement situation; and (4) 16 h per day on a 4–2 schedule appears to be the maximum hours per day a man should work for extended periods.

1.5. *Effects of sleep loss*

The most important concern in sustained work is the effect of sleep loss. When workers perform for extended periods and lose sleep, the accumulating sleep loss degrades performance, mood, and attitude. In instances where limited amounts of intermittent and broken sleep are obtained, that sleep generally is of insufficient quality to restore cognitive functioning and performance to peak levels.

Many writers have discussed the effects of sleep and sleep loss (e.g., Kleitman 1939, Webb 1968, 1982), and there are voluminous reports on human performance in work settings (e.g., Dunnette 1976, Salvendy 1982, 1987, Boff *et al.* 1986). Although attempts to merge the two topics began about the turn of the century, (Patrick and Gilbert 1896), applications of research on the effects of sleep loss and sustained performance in the working world have been rather recent (Englund and Krueger 1985, Krueger and Englund 1985, Krueger *et al.* 1985 b, Krueger and Barnes 1989).

1.5.1. *Lapse hypothesis of sleep loss decrements in performance*

When an individual is required to sustain work and is sleep deprived, it is common to witness occasional 'blocks', or brief periods of no response, that increase in frequency and duration, while performance between blocks is maintained at close to initial levels (Bills 1931). Bjerner (1949) introduced the more general term 'lapses' for 'blocks' and found them in the form of long reaction times coinciding with long periods of reduced arousal. Bjerner (1949) regarded lapses during sleep deprivation as reflecting brief periods of sleep, or a condition like 'microsleeps' (1–10 s), an approach followed by Williams *et al.* (1959) in their seminal work on the topic.

Williams *et al.* (1959) kept subjects awake for at least 72 h, and sometimes as long as 98 h. In simple experimenter-controlled (machine-paced) reaction time (RT) tests, they found the difference between slowest and fastest responses became greater as lapses increased in duration; and as lapses increased in frequency, the distribution of reactions showed more long RTs. They showed that sleep deprived subjects are capable on some trials of coming very close to their best RTs of earlier baseline periods, but that there is an enormous increase in duration of the longest reaction times. The subjects' poorest performances became progressively worse, even though their best performances remained close to original levels. Continuing sleep loss produced an increase in frequency and duration of lapses, but performance between lapses was at an acceptable but generally reduced level. Sleep loss also consistently produced impaired performance on experimenter-controlled vigilance tasks using auditory, visual, or vibratory stimuli. Performance lapses were related to speed and only indirectly to accuracy as errors of omission. As sleep loss progressed, errors began to appear earlier in the task and the benefits from an initial effort, or a break between parts of the task, became increasingly short lived.

On a variety of tasks (addition, communication, and concept attainment) in which the subject controlled the time at which a response was made or the interval between responses (worker-paced jobs), the consistent result was a change, not in accuracy, but in the rate of performance or speed of response. These slower speeds stemmed primarily from an increase in the frequency and duration of lapses. They were also affected by the same task properties that gave rise to little or no change in accuracy: the subject had an unlimited response time which allowed for the delay of a response or for the correction of errors, and the usual orientation toward correctness which prompted the subject to sacrifice speed for accuracy, (Williams *et al.* 1959).

Williams *et al.* (1959) studied additional conditions that affected decrements attributable to the lapse hypothesis, and found that: (1) altering the level of motivation, especially by providing knowledge of results, tended to reduce impairment, but the differences were small and inconsistent; (2) exhorting subjects to perform better produced only slightly better performance and only on single stimulus tasks; (3) increasing the complexity of a communication receiving task resulted in more errors of omission; (4) with sleep loss, subjects frequently failed to acquire and recall information quickly, and this led to an increasing number of items 'missed'; (5) with increasing sleep loss, there usually is a decline in EEG alpha amplitude associated with errors of omission; and (6) there is significant recovery after sleep.

In a more recent 72-h total sleep deprivation study (Thorne *et al.* 1983, Babkoff *et al.* 1985), subjects were tested hourly on a variety of perceptual and cognitive tasks requiring 30 min to complete. The tasks, ranged from the simple to the complex, including logical reasoning, memory, serial addition and subtraction, pattern recognition, complex verbal processing, and vigilance. As sleep deprivation continued, the average time on task increased at an accelerating rate. The rate of increase differed among tasks, with longer tasks showing greater increases than shorter ones and confounding sleep deprivation and workload effects. Performance on all tasks deteriorated in parallel with a deterioration in mood, motivation, and initiative. Performance on the cognitive tasks declined roughly 25% for every 24 h of semicontinuous work without sleep. As the subjects became more tired, the cognitive testing, which initially took only 30 min out of each hour, took longer to complete, so by 72 h subjects were working continuously. Declines in cognitive performance correlated with circadian fluctuations in body temperature.

There are many other studies on the effects of sleep loss on sustained performance, including those which point out that workers do not adapt well to restricted sleep schedules though they may think they do (Carskadon and Dement 1979, 1981); that prior experience with sleep loss does not train one to cope with the deleterious effects of sleep loss on performance (e.g., Webb and Levy 1984); that higher rates of sleep fragmentation lower the recuperative value of the sleep and minimize restorations in cognitive functioning (Stepanski *et al.* 1984); that particular sleep stages are relatively unimportant to performance (Johnson *et al.* 1974); that naps often benefit subsequent task performance (Naitoh *et al.* 1982, Naitoh and Angus 1987, Dinges *et al.* 1985); and the degree to which sleep loss impairs performance on a variety of tasks increases with age (Webb and Levy 1982, Webb 1985).

1.6. *Sustained and continuous performance studies*

Some military studies have been carried out using actual work schedules necessitating sleep loss. Drucker *et al.* (1969) required 2-man teams to operate continuously at compensatory tracking and target-identification tasks for a 48-h period. Significant performance decrements were observed with both tasks, especially during the usual sleep period. Rotation of tasks between members of teams did not enhance performance or abate deterioration. In a series of SUSOPS field studies, 36 to 48 h in length, Banks *et al.* (1970) reported fairly stable performance on three infantry tasks (surveillance-target acquisition with a night vision device, rifle firing, and grenade throwing) with individual performance variations gradually attributable to fatigue during vigilance.

Ainsworth and Bishop (1971) studied 4-man tank crews doing offensive, defensive, and retrograde movements for 48-h SUSOPS. Crews performed communication, obstacle course driving, target surveillance, dynamic gunnery and maintenance without serious performance decrements. The authors concluded that activities demanding a protracted high level of alertness or complex perceptual-motor activity, such as moving surveillance and driving, were most sensitive to loss of sleep, that tank crew performance was not affected significantly by circadian periodicity and that although it was acceptable for a 48 h stretch without sleep tankers slowed down their overall performance of tasks. Caille *et al.* (1972) found 64 to 72 h of sleep loss did not severely impair the overall 'fighting capabilities' of well trained and highly motivated naval enlisted men. Of several tasks, only long term memory and decision making showed performance decrements.

Morgan *et al.* (1974) studied work efficiency during a 7-day study consisting of 4 h on duty, followed by 4 h off duty, 4 h more on duty, and then 12 h off duty for each of 2 days; then continuous work for 48 h followed by a 24-h period of rest, and 2 additional days of work according to the 4–4–4–12 schedule. Performance during the embedded 48-h SUSOPS was influenced significantly by circadian rhythm. Decrements first occurred after 18 h of continuous work and performance decreased to an average of 82% of baseline during the early morning hours of the first night. It then improved to 90% of baseline during the second day, but decreased to approximately 67% that night. All performance recovered to baseline levels following the 24-h period of rest.

In another study, three parachute regiment platoons participated in a field study of continuous infantry operations (Haslam *et al.* 1977, Haslam 1985 b, Haslam and Abraham 1987). One platoon was permitted no sleep, another was allowed 1·5 h sleep, and the third was permitted 3 h sleep per 24 h in a 9-day exercise. Military performance, including shooting, weapon handling, digging, marching, and patrolling, was assessed throughout. Subjects completed a daily battery of cognitive tests, which included map plotting, encoding/decoding, short term memory, and logical reasoning.

The platoon allowed no sleep was militarily ineffective after 3 nights without sleep and all members of the platoon withdrew from the exercise after 4 nights without sleep. Thirty-nine percent of the 1·5 h-sleep platoon withdrew after 5 nights and this platoon was judged to be militarily ineffective after 6 days. The platoon sleeping 3 h per night remained effective the entire 9 days.

In a related study, infantry soldiers were scheduled no sleep for 90 h of continuous activity, and then allowed 4-h blocks of sleep in every 24 h for the next 6 days (Haslam 1978, Haslam and Abraham 1987). All subjects completed these trials. In both studies the main effect of sleep deprivation was psychological rather than physiological; mental ability and mood deteriorated, whereas physical fitness did not. Vigilance and the more difficult and detailed cognitive tasks deteriorated most. After three nights without sleep, performance on these tasks deteriorated to near 50%, and in some cases as low as 35% of control values at which point they were judged to be militarily ineffective. Simple and well learned tasks, like weapon-handling tests, suffered little. Vigilance shooting, an event paced task, deteriorated markedly, while performance on a self-paced shot grouping task did not.

In general, there was a rapid decrement in the cognitive tests over the first 4 days of sleep loss, after which performance tended to level out for those subjects remaining in the field. As tiredness increased, sergeants found a more relaxed style of leadership to be appropriate, and exhortation to be better than direct orders. In the later stages of sleep-deprivation, most soldiers felt attention to detail was no longer required of them and personal hygiene and self-care deteriorated.

In this second study, 4 h of sleep on each of 3 nights was sufficient to restore performance and mood to the average control level on the following day. After the first 4-h block of sleep, performance improved to 60% of control values and after the third 4-h block of sleep, performance improved to 80% of control values where it remained for the last 3 days of the trial. The exception to this overall positive effect was that performance on the cognitive tests administered immediately after awakening remained low (sleep inertia) even after several nights in which 4 h of sleep were obtained. The utility of obtaining 4 h of sleep within each 24-h period for restoring and sustaining performance was confirmed (Haslam 1982, 1985 a). Four hours of sleep divided into 4 1-h blocks was as restorative as 4 h of continuous sleep. Further, after 3 days without sleep, anticipation of a 2-h nap produced a substantial improvement in performance.

In a study of pilot performance during extended flight operations, six aviators flew a helicopter for 11·5 h per day on each of five 20-h workdays with 3·5 h of sleep per night (Kimball and Anderson 1975, Lees *et al.* 1979). These pilots flew 32 different manoeuvres once per hour during their workday. In a second study, pilot–copilot crews flew 14 helicopter simulator hours per 20-h workday for 5 days, sleeping about 4 h each night (Krueger *et al.* 1985 a). All 12 pilots completed these two 5-day studies without major incident. However, while the psychomotor component of flight performance did not degrade to unacceptable levels, by the fourth day, pilots adopted a more passive flight control strategy, making less frequent, but larger cyclic control inputs. More important, by the fourth day pilots made occasional errors of omission (possibly lapses), like forgetting to make safety or communication checks, and simulator copilots occasionally fell asleep in their less active role as navigator. These studies indicate with just 3·5 to 4 h sleep per night, trained soldiers can control and manoeuvre complex man–machine systems for 12–14 h a day for at least 5 days, albeit at a cost in terms of efficiency and safety.

Artillery fire direction centre (FDC) teams participated in a 3-day simulation of sustained tactical battle operations working on maps, plotting preplanned and unplanned targets, with concurrent fire missions that often were superimposed with calls for preplanned fire (Bandaret *et al.* 1981). Degradation of performance was evident within the first 24–48 h. All four teams elected to withdraw from the study by 48 h. Teams made more errors as time passed, but generally remained effective until the time of their withdrawal. Performance of individual self-initiated activities (e.g., working out preplanned fire missions, revising preplanned data on the basis of new information, and keeping up the situation map) deteriorated most. As in the Haslam studies, teams in which leadership and cohesion were good, functioned better, and persevered longer. Thus, generally it can be said that under sleep deprived conditions, a well-led unit may outperform an indifferently led one. However, superior leadership cannot overcome large quantitative differences in sleep obtained or lost (Belenky *et al.* 1987).

A number of driver fatigue studies (e.g. Brown 1965, Brown *et al.* 1967) have concluded that a continuous 12-h period of driving during the normal working day need not affect either perceptual or motor skills adversely. In a simulation study of automobile driving, sustained performance was studied in 15 young adult males who performed a primary tracking task and a variety of secondary tasks over a 15-h period (Ellingstad and Heimstra 1970). Tracking performance decreased significantly over the course of the study. Secondary-task performances were markedly variable over the 15 h, with no clearly established decrements in performance.

Thus, some sustained operations studies produce seemingly conflicting results, possibly suggesting more attention to individual differences is needed. Furthermore, wide differences in study designs, the degree of experimental control, the fidelity of simulation, the measurement methodology and technology, and the choices of dependent variables make it difficult to determine general principles and to extrapolate from basic studies to predictions of real-world sustained work performance. More quality research needs to be conducted in this area (Englund and Krueger 1985, Krueger and Englund 1985) since these findings have implications for theoretical models of sustained perceptual and cognitive functioning and have obvious application to sustained military, but perhaps to civilian industrial operations as well.

1.7. *Naps and their effects on sustained performance*
Conventionally, naps mean brief sleep periods, especially during the day, to supplement or replace sleep normally obtained at night. Naps serve as a break, a change of pace from the work being accomplished and if they are long enough to provide restorative sleep, they can refresh the worker. It is common practice for workers in some countries to take a siesta in early afternoon. The length, number, quality, and placement of naps interspersed into continuous work/rest schedules, are important for their effects on sustained performance.

Many authors use the term 'nap' to refer to a short period of sleep even when that is the only sleep obtained in a 24-h period. Thus, a 'nap' or a 'short night's sleep' can differ depending upon the literature one reads. Most sleep researchers agree naps restore degraded functioning and that 4–5 h of sleep should be taken in an uninterrupted period to prevent impaired performance. The continuity of sleep theory (Naitoh and Angus 1987) postulates that continuous sleep has greater recuperative power, based on notions of importance of the duration of various stages of sleep obtained. If sleep occurs in short pieces over 24-h it is much less effective, even if the total sleep time is the same (Naitoh 1981, Naitoh and Angus 1987, Hartley 1974).

Naitoh and Angus (1987) discuss naps in the context of sleep management, a programme to maintain human functioning by preplanned napping during prolonged work periods. They contend a nap is effective in maintaining performance and mood when it is taken prophylactically before anticipated sleep loss and fatigue. However, immediately upon awakening from a nap, performance decrements may occur, sometimes up to 15 or 20 min after awakening. These sleep inertia effects are evident for a wide variety of tasks (Dinges *et al.* 1985) and should be anticipated if a worker is expected to wake quickly and respond to immediate performance expectations. Researchers present conflicting interpretations about the effects of the duration of naps on performance, the recommended timing or placement of naps in the work/rest schedule, the quality of rest/sleep obtained during naps, and sleep inertia effects (Dinges *et al.* 1988).

1.8. *Pharmacological intervention*
Various military research programmes have and are examining the potential for pharmacological intervention to sustain or enhance performance in CONOPS. Hypnotic drugs can induce sleep in the off-duty shift. Baird *et al.* (1983), documented use of a benzodiazepine (temazepam) for aviation crews in the off-duty hours to induce sleep before returning to flying duties in the Falkland conflict. Storm and Parke (1987) cite sleep and operational performance data from US Air Force fighter pilots after temazepam induced sleep in the off-duty period. The Israeli forces administered hypnotics to promote sleep among troops (passengers) during the air deployment portion of the Entebbe raid, and O'Donnell (1986) proposes the use of benzodiazepines in military aerial deployments across multiple time zones as a prophylactic to jet lag (O'Donnell *et al.* 1988).

The major concerns with hypnotics include the amount and quality of sleep/rest obtained with particular drug doses, whether or not users can awaken easily during drug-induced sleep and quickly respond normally in event of emergency. By contrast, some researchers argue for use of 'nonsedating' sleeping aids like the amino acid 1-tryptophan for military use (Spinweber 1986). Other concerns include whether there are lingering effects on performance after one awakens from the sleep period; and the effects of repeated use.

In select circumstances, stimulants can be used to maintain alertness to meet extended performance demands. Jones (1985) suggests that during the Second World War Soviet personnel used drugs to stave off fatigue and drowsiness, and to improve memory and concentration. During the Vietnam War, methylphenidate and dextroamphetamine were carried by US long range reconnaissance patrol soldiers. Jones (1985) says these soldiers found the most efficacious use to be upon completion of a mission when fatigue developed and rapid return to base camp was desirable. Other than mild rebound depression and fatigue after the drug was discontinued, no additional adverse effects were reported. However, Holloway (1974) has reported problems with abuse of stimulants by the soldiers brought about their discontinuation.

Concerns with stimulant drugs include their wide-ranging and not well-understood effects on bodily biochemistry and physiology, and especially their effects on performance. Some stimulants distort perception and affect safety, produce rebound effects like depression and fatigue, require subsequent increased doses to produce the same effects, and are likely to be addicting.

1.9. *Other factors*
Worker performance during SUSOPS is influenced by the interaction of several other factors: prior rest quantity, physical fitness, endurance, environmental conditions, number of sustained work episodes, time of day of performance, task type, workload, and motivation (Englund *et al.* 1983). For example, although one should be rested before engaging in sustained operations, we cannot store sleep, but prior rest will stave off the detrimental effects longer. All other things being equal, the state of physical fitness of individuals will affect stamina in many sustained work efforts, particularly those with extensive physical components. Noise can lessen the effects of sleep loss in auditory vigilance tasks. Tasks of high interest can prolong motivation to perform.

2. Discussion

Theoretical research must deal with SUSOPS/CONOPS stresses as they affect individual information processing. From this review of the issues it should be clear that psychological models of sustained performance must account for continuing operating demands of long work stints, for fatigue, sleep loss, circadian rhythms etc., and delineate performance predictions as functions of task type, account for scheduling of rest breaks, levels of motivation and other intervening variables.

A variety of important SUSOPS/CONOPS research questions remain. What are the tradeoffs in efficiency, productivity, and effectiveness if one works longer work-shifts, albeit at reduced efficiency, in situations where faster performance is not so critical, but hiring and training additional employees would be cost prohibitive? Do we raise the overall productivity level of the individual worker a sufficient amount to justify having him or her work those extended hours? What implications are there for flexitime employees who schedule 15 h or more work per day to complete their 'work week' in 3 days or less? Is there a point at which work efficiency reaches diminishing returns? Ultimately, there is the question of whether or not there really is an optimum work week. It should be clear that sustained operations, whether they are planned or unplanned, bring about new research concerns of worker stress and raise issues of productivity and performance effectiveness.

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