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The effects of task duration and work-session location on performance degradation induced by sleep loss and sustained cognitive work

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Studies attempting to estimate the degree of performance degradation resulting from sleep loss typically use relatively long-duration tasks that are distinctly separate from ongoing activities. Since long-duration tasks are not practical for assessing the performance degradation induced by sleep loss in field settings, this study was designed to examine whether the results of short-duration (1-min) tasks were markedly different from those of long-duration (10-min) tasks with respect to detecting performance changes during a 54-h period of sleep loss and sustained cognitive work. Performance changes also were examined as a function of the location of tasks within work sessions by comparing performance on 1-min tasks that were placed within work sessions with those tasks that immediately followed short rest periods. The results showed that short- and long-duration tasks were equally sensitive to sleep loss. In addition, once sleep-deprivation effects began to emerge, it was found that performance on short-duration tasks within work sessions showed significantly more impairment than performance on tasks that followed rest breaks. These results suggest that task duration is not a critical factor for detecting performance degradation induced during continuous work experiments but that the location of tasks within work sessions is critical for accurately assessing expected performance.

The degree to which cognitive tasks are sensitive to sleep loss is thought to be determined by a number of task-specific factors as well as other psychological, environmental, and chronobiological considerations (e.g., see Johnson, 1982). Task duration is one factor thought to influence the sensitivity of cognitive tasks to detecting performance impairment during sleep loss (e.g., Johnson, 1979; Johnson & Naitoh, 1974; Naitoh & Townsend, 1970; Wilkinson, 1965, 1969). It has been suggested that, as sleep deprivation periods become shorter, task durations must increase in order to detect impaired performance due to sleep loss. Wilkinson (1961, 1964) found that after moderate sleep deprivation of only one night, significant performance impairment on serial reaction time and vigilance tasks could be detected, but only during the last half of these 30-min tasks. Williams, Lubin, and Goodnow (1959) also demonstrated the interaction of sleep loss and task-duration effects. They found that following long periods of sleep loss (72 h), auditory vigilance was impaired after only 2 min, but when sleep loss was reduced (48 h), impairment of performance did not occur until later (6 min) in the task. Following moderate sleep loss (24 h), performance was unimpaired after 10 min on the task. Such results led Wilkinson (1968) to the conclusion that, in order for a test to be sensitive to moderate sleep deprivation, it must be prolonged to 30 min and should preferably be 1 h in duration.

Since this early work, only a few investigators have examined the relationship between task duration and performance degradation during sleep deprivation. Donnell (1969) tested subjects for 1 h on the Wilkinson (1958) addition task following 32 h and 64 h of sleep deprivation. After 32 h, accurate performance did not differ from baseline until 50 min of testing had elapsed; however, accurate performance showed significant impairment after only 10 min following 64 h of sleep loss. When the dependent variable was the number of additions attempted rather than accuracy rates, the same relationship between task duration and performance degradation remained, but significant impairment was measurable much earlier in the task; significant impairment occurred after only 10 min of testing following 32 h of sleep loss and after only 6 min following 64 h of sleep loss. These data suggest that shorter duration tasks could be sensitive to moderate sleep loss given appropriate measurement techniques.

Lisper and Kjellberg (1972) further examined the relationship between task duration and sleep loss using only a 10-min simple auditory reaction time task and a moderate amount of sleep loss (one night). Their results showed that this 10-min task was sufficiently sensitive to detect the adverse effect of one night of sleep deprivation on performance but again revealed that the reaction time performance was impaired primarily during the last few minutes of the 10-min task. Recently Wilkinson and his colleagues (Glenville, Broughton, Wing, & Wilkinson,

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1978; Glenville & Wilkinson, 1979; Wilkinson & Houghton, 1975, 1982) have also demonstrated that 10-min simple and choice reaction time tasks were sensitive to moderate sleep deprivation as well as to other factors such as shift work (Glenville et al., 1978).

These studies demonstrate that tasks of shorter duration than suggested by Wilkinson (1968) are sensitive to moderate sleep loss, but it still appears that task duration should be on the order of 10 min to be sensitive, because only the last few minutes of the task may reveal impaired performance. An exception, however, is a recent study by Mullaney, Kripke, Fleck, and Johnson (1983), in which subjects worked continuously on a battery of 3-min tasks and subjective questionnaires that were repeated every 10 min for 42 h. These short tasks revealed degraded performance after approximately 18 h of sleep loss. As the authors point out (p. 643), however, this effect may have been exaggerated by other nontask factors such as the strong element of monotony that existed in their study (cf. Wilkinson, 1964).

If individual tasks must be on the order of 10 min in duration to be sensitive to moderate sleep loss, assessing changes in performance in operational settings through the use of such long-duration tasks may not be practical. More importantly, these long-duration tasks may lead to unreliable estimates of performance efficiency due to other factors. For example, if subjects can easily discriminate testing periods from their usual work environments (and find the tasks interesting), they may be more highly motivated to perform during periods of testing than during their regular duties. If subjects can draw on unused reserves, or capacity, to enhance performance during these testing periods, performance may be spuriously inflated. However, the converse may also be true. If subjects find the test procedures uninteresting, or disruptive in terms of their primary duties, estimates of performance degradation may be falsely exaggerated. Minimizing task duration may make the inclusion of test procedures in operational settings both more practical and a more accurate reflection of performance levels.

The sleep-loss study reported here was designed to contrast the sensitivity of short- (1-min) and long- (10-min) duration tasks with respect to detecting the effects of sleep deprivation. Tasks with durations as short as 1 min have not been previously tested to determine their sensitivity to moderate amounts of sleep deprivation. In order to examine task-duration effects over varying degrees of sleep loss, a continuous work paradigm was employed in which subjects perform continuous cognitive work under intense workload conditions. In contrast to other paradigms, the continuous work paradigm has at least two major advantages. First, the effects of sleep loss on performance are greater than less continuous and less cognitively demanding paradigms, and second, the continuous nature of the paradigm minimizes motivational changes that may be associated with more intermittent testing schedules (Angus & Heslegrave, 1985). If these relatively unobtrusive short-duration tasks are found to be sensitive to sleep-loss effects, then these tasks could also be used as performance probes to more closely examine the effects of minor fluctuations in performance impairment that may be related to minor changes in workloads and/or fatigue. To examine whether these short-duration tasks are sensitive to such minor fluctuations in impairment due to nontask factors, these short-duration tasks (as well as some self-report measures) were included at various points within the work sessions so that the cumulative effect of the work session on performance could be assessed.

METHOD

Subjects

Twelve female students ranging in age from 19 to 24 years were recruited as subjects from the University of Toronto. They received approximately $4 per hour for their participation, were fully informed about the purpose of the experiment and procedures to be employed, and understood that they were free to withdraw from the experiment at any time.

Apparatus

The experiment was conducted in a self-contained laboratory that was isolated from the normal activities of the building. The laboratory contained the necessary facilities for accommodating the essential needs of both subjects and experimenters for an extended duration. All of the tasks used in this study were generated by a PDP 11/34 computer and displayed on a Digital VT100 video display terminal; subjects responded to all tasks by typing their answers on their individual terminal keyboards. Closed-circuit television and slave monitors were used to visually monitor the subjects and their terminal screens. This continuous inspection allowed experimenters to readily determine whether any subjects fell asleep. If a subject fell asleep, an experimenter immediately woke the subject. Throughout the experiment all subjects wore two four-channel Oxford Medilog (Model 4-24) ambulatory cassette recorders which were configured to continuously record electroencephalographic (EEG), electrocardiographic (ECG), and core-temperature information.

Procedure

Each subject received the same experimental protocol and worked independently of other subjects in separate experimental rooms at her own pace; for convenience, the 12 subjects were run in four groups of 3. Subjects were resident in the laboratory for 4.5 days (from Wednesday morning through Sunday afternoon); blood and urine samples were occasionally collected over this period. All time cues were removed from the subjects and the environment, and interpersonal communication with laboratory staff was kept to a minimum. On Day 1, subjects were briefed on the experiment, given extensive training and practice on the performance tasks, and equipped for continuous ambulatory EEG, ECG, and core-temperature recordings. Training continued until about 8:00 p.m., after which the subjects relaxed, watched a movie, and retired at about 11:00 p.m. They were awakened at 7:00 a.m. Thursday morning, began the experiment at 9:00 a.m., and worked continuously until 3:00 p.m. on Saturday. (The top portion of Figure 1 shows a real-time description of the 54-h sleep-deprivation experiment and the preceding laboratory sleep period.) In the following 24-h recovery period, subjects slept and relaxed according to their own needs.

The bottom portion of Figure 1 shows the work required of subjects in each of the nine identical 6-h performance blocks. Each 6-h block contained four work sessions of exclusively cognitive work that were separated by rest breaks varying from 5 to 20 min during which subjects were permitted to eat, drink, and use the restroom. Each of the four sessions started with the completion of three subjective self-report scales (labeled "SCALES" in Figure 1), which were used to evaluate the subjects' fatigue and sleepiness levels and moods. In order to examine any subjective changes across work sessions, these scales were also presented midway through Session 1 and Session 3.

To examine the influences of task duration on the sensitivity of tasks with respect to detecting performance impairment due to sleep loss, 5 cognitive tasks of long duration (10-min) were presented in Session 2, and 10 identical short-duration (1-min) versions of each of these same performance tasks ("1-min PERFS") were presented in Sessions 1 and 3 for a total of 10 1-min task presentations in each 6-h block. The order of presentation of these 1-min tasks in Sessions 1 and 3 was identical to the order of the 10-min tasks in Session 2 [i.e., serial reaction time, simple iterative subtraction, encoding/decoding, complex iterative subtraction, and logical reasoning (see Figure 1)]. To examine whether there was any cumulative effect of the work session on performance, the five presentations of each of these 1-min tasks were spread across the work session, which enabled us to contrast the first presentation of each task, which followed a rest period, with those presentations of the tasks that occurred in the middle of a work session.

All of the tasks and the self-report scales are described in detail in Angus and Heslegrave (1985). For all tasks, subjects were instructed to work as quickly and accurately as possible. All tasks required typed keyboard responses and were scored for accuracy; also, the time to complete each answer was recorded. The three self-report scales used were the Fatigue Checklist (Harris, Pegram, & Hartman, 1971), the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), and the Naval Health Research Center's Mood Scale (Johnson & Naitoh, 1974). For all scales, greater scores reflected less subjective fatigue, more subjective sleepiness, and more positive or more negative moods.

The five performance tasks included in the test battery were the serial reaction time, simple iterative subtraction, encoding/decoding, complex iterative subtraction, and logical reasoning tasks. Briefly, the four-choice serial reaction time task ("SERIAL") required subjects to translate serially presented stimuli, which were meaningful units of information, into spatially organized motor responses. The simple iterative subtraction task ("SUBTR simple") required subjects to subtract a randomly chosen single-digit number between 5 and 9 from a randomly chosen three-digit number from 500-999 and then iteratively subtract that same subtrahend from each successively obtained difference for 60 sec. In the encoding/decoding task ("EN/DECODE"), the encoding portion required subjects to transform a six-digit map coordinate into a four-letter code using a preestablished set of rules; decoding required the reverse procedure. The complex iterative subtraction task ("SUBTR difficult") required subjects to subtract 9 from a randomly chosen three-digit number from 500-999 and then iteratively subtract the next subtrahend (from the set 9 through 5) from each successively obtained difference for 60 sec. The logical reasoning task ("LOGICAL REASONING") required subjects to understand sentences of varying syntactic complexity and evaluate their veracity.

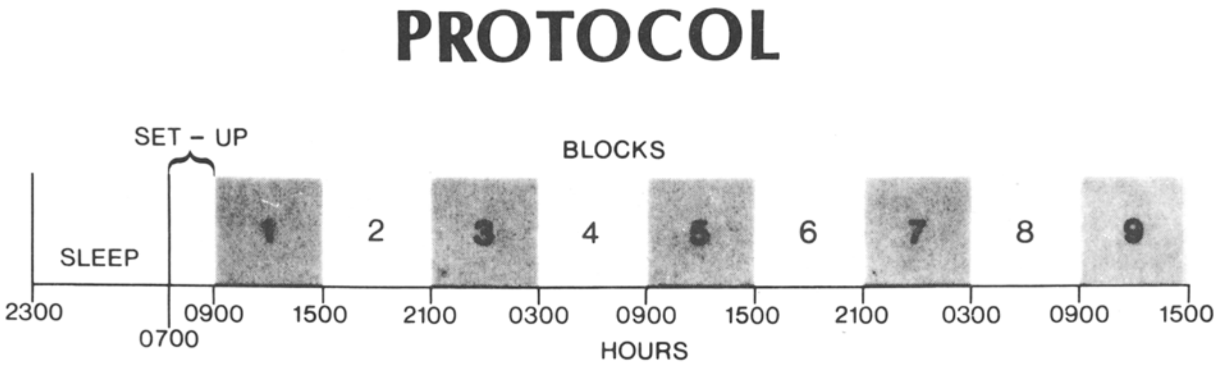
RESULTS

Because participants were initially selected on the basis of their fitness levels (high/low), and because all responses to tasks were scored for accuracy (correct/wrong), both fitness and accuracy were included as factors in the analyses to remove the variance attributable to these sources.

Task Duration

Although there were five long-duration (10-min) tasks in Session 2, only the serial reaction time and logical reasoning tasks can be contrasted with the dispersed 1-min tasks to examine how task duration influences the sensitivity of these tasks with respect to detecting performance degradation due to sleep deprivation. The two subtraction tasks cannot be contrasted because a new subtraction problem was presented during each min of the 10-min task, thereby removing the continuous nature of the task. (Previous work demonstrated that subjects could not effectively perform iterative subtraction for periods much longer than 60 sec.) It was also found that when the encoding/decoding task was reduced to 1 min in duration, subjects were unable to solve both an encoding and decoding problem during each minute (see Angus & Heslegrave, 1985); this task will not be discussed further.

The serial reaction time and logical reasoning tasks were used to examine three questions concerning task duration. (1) Does task duration interact with sleep-deprivation effects in long-duration (10-min) tasks (i.e., is performance impairment detectable earlier in the task as sleep loss continues)? (2) Are short-duration (1-min) tasks sensitive to moderate sleep deprivation under conditions of continuous, intense workload? (3) Are short-duration tasks less sensitive than longer tasks to sleep deprivation under these conditions? Before addressing these questions, however, an analysis was conducted to confirm that these 10-min tasks were indeed sensitive to moderate sleep deprivation,



PROTOCOL

6 HOUR BLOCK

	TIME (approx)	TASKS	
1	0 - 05	SCALES	Session 1
	5 - 10	1 min. PERFS	
	10 - 25	MESSAGES	
	25 - 30	1 min. PERFS	
	30 - 45	MESSAGES	
	45 - 50	1 min. PERFS	
	50 - 05	MESSAGES	
2	05 - 10	SCALES	
	10 - 15	1 min. PERFS	
	15 - 30	MESSAGES	
	30 - 35	1 min. PERFS	
	35 - 45	PLOT S1 • • • • BREAK	
	45 - 50	SCALES	Session 2
	50 - 60	SERIAL	
3	00 - 10	SUBTR (simple)	
	10 - 20	EN/DECODE	
	20 - 30	SUBTR (difficult)	
	30 - 40	LOGICAL REASONING	
	40 - 50	STM (digit span)	
	50 - 60	PLOT S2 • • • • BREAK	
4	0 - 05	SCALES	Session 3
	05 - 10	1 min. PERFS	
	10 - 20	MESSAGES	
	25 - 30	1 min. PERFS	
	30 - 45	MESSAGES	
	45 - 50	1 min. PERFS	
	50 - 05	MESSAGES	
5	05 - 10	SCALES	
	10 - 15	1 min. PERFS	
	15 - 30	MESSAGES	
	30 - 35	1 min. PERFS	
	35 - 55	PLOT S3 • • • • BREAK	
	55 - 60	SCALES	Session 4
6	00 - 10	SIGNAL DETECTION	
	10 - 20	MEMORY (training)	
	20 - 50	VIGILANCE	
	50 - 55	MEMORY (recall)	
	55 - 60	• • • • • • • • • • • BREAK	

Figure 1. Experimental design. The top of the figure shows the experimental protocol including the preexperimental night's sleep and the specific placement of the 6-h experimental blocks. The bottom of the figure shows the experimental activities and their specific temporal occurrence during each identical 6-h block.

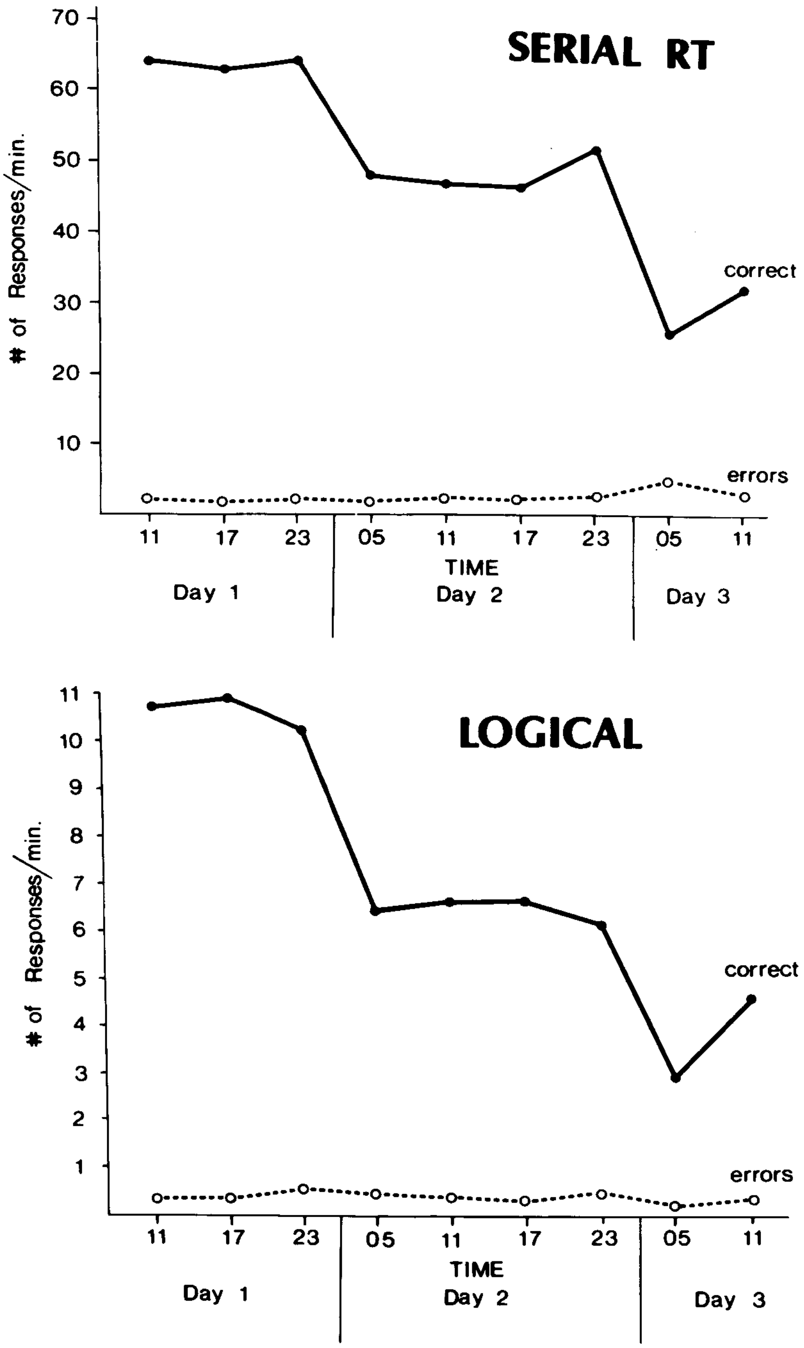


Figure 2. Performance tasks. The figure shows the changes in cognitive performance over the nine experimental blocks for the 10-min serial reaction time (upper) and logical reasoning (lower) tasks.

since tasks of this limited duration have not always been sensitive under such conditions.

Figure 2 shows the significant decline in performance (summarized in terms of responses/minute) for the reaction time [F(8,80) = 42.43, p < .001] and logical reasoning [F(8,80) = 28.93, p < .001] tasks over the nine 6-h blocks in the experiment, shown in the upper and lower portions of the figure, respectively. The significant change in performance can be attributed to a decline in the number of correct responses made per minute rather than to an increase in the number of errors, as indicated by the interaction between accuracy (correct responses vs. errors) and experimental blocks for both the reaction time [F(8,80) = 41.55, p < .001] and logical reasoning [F(8,80) = 24.55, $< .001$] tasks. Therefore, these 10-min tasks were significantly affected by a moderate amount of sleep deprivation. It is also interesting to note that there were significant declines in accurate responding during each of the two nights of sleep deprivation, with performance remaining stable between these periods of decline (e.g., see the relatively constant level of performance from 5:00 a.m. to 11:00 p.m. on Day 2 in Figure 2).

To determine whether the sleep-loss effect interacted with task duration, the minute-by-minute change in performance over the 10-min duration was analyzed for both the serial reaction time and logical reasoning tasks over the nine experimental blocks. The results showed that there was a significant time-on-task effect, with performance systematically declining over each min of the 10-min tasks for both the serial reaction time [F(9,90) = 38.93, $p < .001$] and logical reasoning [F(9,90) = 44.35, $p < .001$] tasks. As expected, the decline in performance interacted with accuracy for both the serial reaction time [F(9,90) = 32.53, $p < .001$] and logical reasoning [F(9,90) = 33.88, $p < .001$] tasks, indicating that accurate responding declined over the 10-min duration for both tasks while errors remained stable. The minute-by-minute change in accurate performance is illustrated in Figure 3 for the serial reaction time (upper) and logical reasoning (lower) tasks, using the data from the initial performance of subjects on Day 1 and for their performance at 5:00 a.m. on Days 2 and 3 to represent the change in performance; the latter two curves illustrate the minute-by-minute change in accurate performance which followed significant drops in performance. An analysis of these data supports the assertion that accurate performance significantly declined over the 10-min duration of the task for both the serial reaction time [F(9,90) = 26.02, $p < .001$] and logical reasoning

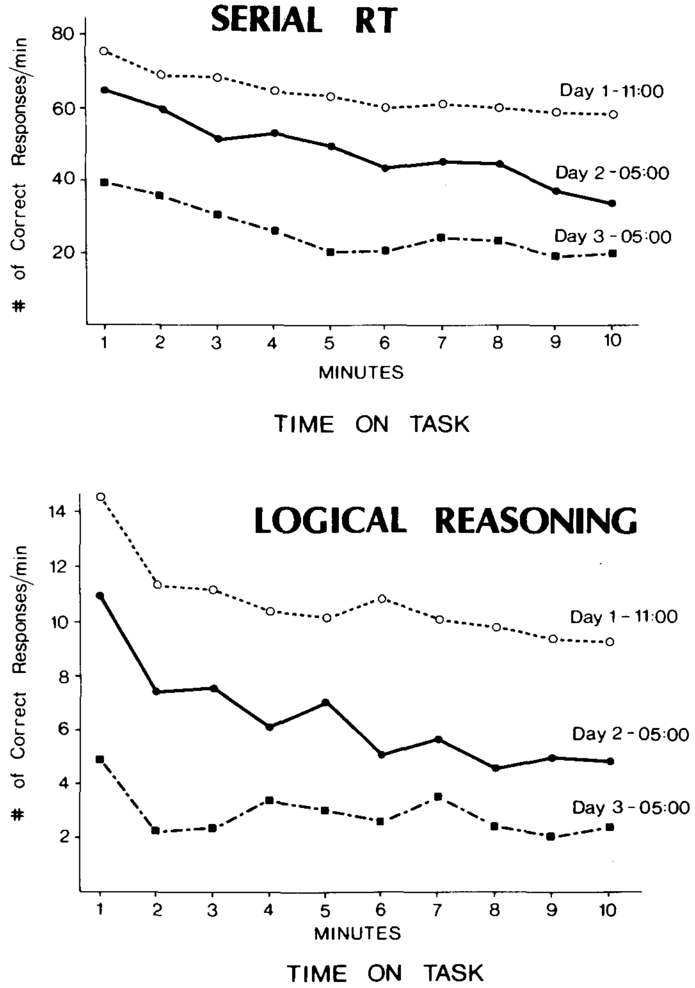


Figure 3. Performance tasks. The figure shows the min-by-min accurate performance on the serial reaction time (upper) and logical reasoning (lower) tasks for the initial performance on Day 1 and for the performance at 5:00 a.m. on Days 2 and 3 which followed significant drops in performance efficiency.

[$F(9,90) = 13.10$, $p < .001$] tasks, and the levels of performance for these three sampled periods were significantly different for both tasks [serial reaction time, $F(2,20) = 86.69$, $p < .001$; logical reasoning, $F(2,20) = 38.10$, $p < .001$]. It must be emphasized, however, that there was no interaction between task-duration (i.e., minutes) and sleep-deprivation (i.e., experimental blocks) effects for either task (serial reaction time, $F = 1.4$; logical reasoning, $F = 1.8$). This lack of an interaction occurred despite the fact that the two tasks revealed different topographical changes over the 10-min period. The serial reaction time task showed a steady progressive decline over the 10-min period, while the logical reasoning task showed a marked decline from the 1st min to the 2nd min.

Given that the task-duration and sleep-deprivation effects do not interact significantly in the long-duration tasks, short-duration (1-min) tasks should be sensitive to moderate sleep deprivation under these current conditions of continuous, intense work. The upper half of Figure 4 shows the mean accurate performance on the five 1-min serial reaction time tasks that occurred in each of the 18 sessions of the experiment (i.e., Sessions 1 and 3 of each experimental block) along with the mean accurate performance on the 10-min task. The lower half of the figure shows the same data for the logical reasoning task.

Figure 4 shows the significant decrement in accurate performance on the short-duration serial reaction time task that occurred over the experiment [$F(17,170) = 39.66$, $p < .001$]. (Because errors did not change in these 1-min tasks, as indicated by the interaction between accuracy and sessions [$F(17,170) = 44.52$, $p < .001$], only changes in accurate performance are shown in the figure.) For the logical reasoning task, the results were similar. Significant decrements in performance on this task also occurred over the 18 sessions [$F(17,170) = 30.77$, $p < .001$]; these decrements were attributable to a decline in accurate responding over sessions, as indicated by the interaction of accuracy with sessions [$F(17,170) = 24.56$, $p < .001$].

Figure 4 also shows the topography of the correct responses from the short-duration (1-min) tasks and contrasts these data with the results from the long-duration (10-min) versions of the same tasks. (In order to contrast these tasks of different duration in the same analysis, the 10 1-min, short-duration tasks were considered to be 10 1-min periods of the task within the same experimental block. The short-duration tasks were then equivalent to the long-duration task for analysis purposes, with 10 1-min periods in each of the nine experimental blocks.) As can be seen in Figure 4, the 1-min tasks show essentially the same response topography over the experiment as the 10-min tasks, and thus show the same sensitivity to sleep loss. Although accurate responding was significantly higher in the 1-min serial reaction time [$F(1,10) = 54.74$, $p.,001$] and logical reasoning [$F(1,10) = 99.67$, $p.,001$] tasks because of task-duration effects that occurred during the long-duration task, there was no interaction between task duration (1-min vs. 10-min tasks) and the change over the nine experimental blocks [serial, $F(8,80) = 1.47$; logical reasoning, $F(8,80) = 1.14$]. These results further demonstrate that the 1-min tasks showed equivalent sensitivity with respect to detecting sleep loss when compared with the 10-min tasks. Together, these results bring into question the need for tasks of long duration in continuous, high-cognitive demand environments.

Work-session Location

Because short-duration tasks were found to be sensitive to sleep loss, it was reasonable to contrast a variety of self-report scales and performance tasks that occurred at the beginning of work sessions after a short rest with less obtrusive scales and short-duration tasks that were embedded within work sessions. If the rest period had a beneficial effect and/or the work session had a cumulative detrimental effect, these estimates of mood and performance should be sensitive to these effects.

To contrast data from the subjective self-report scales that occurred at the beginning of a work session (following a rest period) with those that occurred during a work session, the fatigue, sleepiness and mood data from the beginning and middle of Sessions 1 and 3 in each block were compared. Figure 5 shows these results. Although all scales showed significant changes over the course of the experiment, the scales also showed differential estimates of the subjects' reported levels of fatigue, sleepiness, and mood depending on when these subjective feelings were assessed. Only after sleep-deprivation effects began to emerge following the first 18 h of sleep deprivation, subjects reported feeling worse on scales administered within a work session in contrast to those administered after a short rest period, regardless of the time of day. In the upper left-hand panel of Figure 5, the data show that after 18 h, subjects reported feeling significantly more fatigued during the work session than following a short rest [$F(1,10) = 53.12$, $p < .001$]. This difference became pronounced during the first night, but was maintained to a lesser degree over the remainder of the experiment, as indicated by the significant interaction between the two curves over the 18 sessions of the experiment [$F(17,170) = 2.63$, $p < .005$].

The lower left-hand panel of Figure 5 shows that the subjects reported significantly greater subjective sleepiness when asked during a work session [$F(1,10) = 16.05$, $p < .005$], and that a significant interaction between the two curves occurred over the experiment [$F(17,170) = 2.97$, $p < .005$]. The right side of the figure shows the changes in positive and negative moods. Subjects reported significantly lower positive moods [$F(1,10) = 13.70$, $p < .005$] and greater negative moods [$F(1,10) = 30.03$, $p < .001$] during the work sessions. These differences again emerged only after 18 h, as indicated by the significant interaction with time for both the positive [$F(17,170) = 2.02$, $p < .05$] and the negative [$F(17,170) = 4.03$, $p < .001$] moods. For these subjective data, once the initial decline in subjective state commenced at

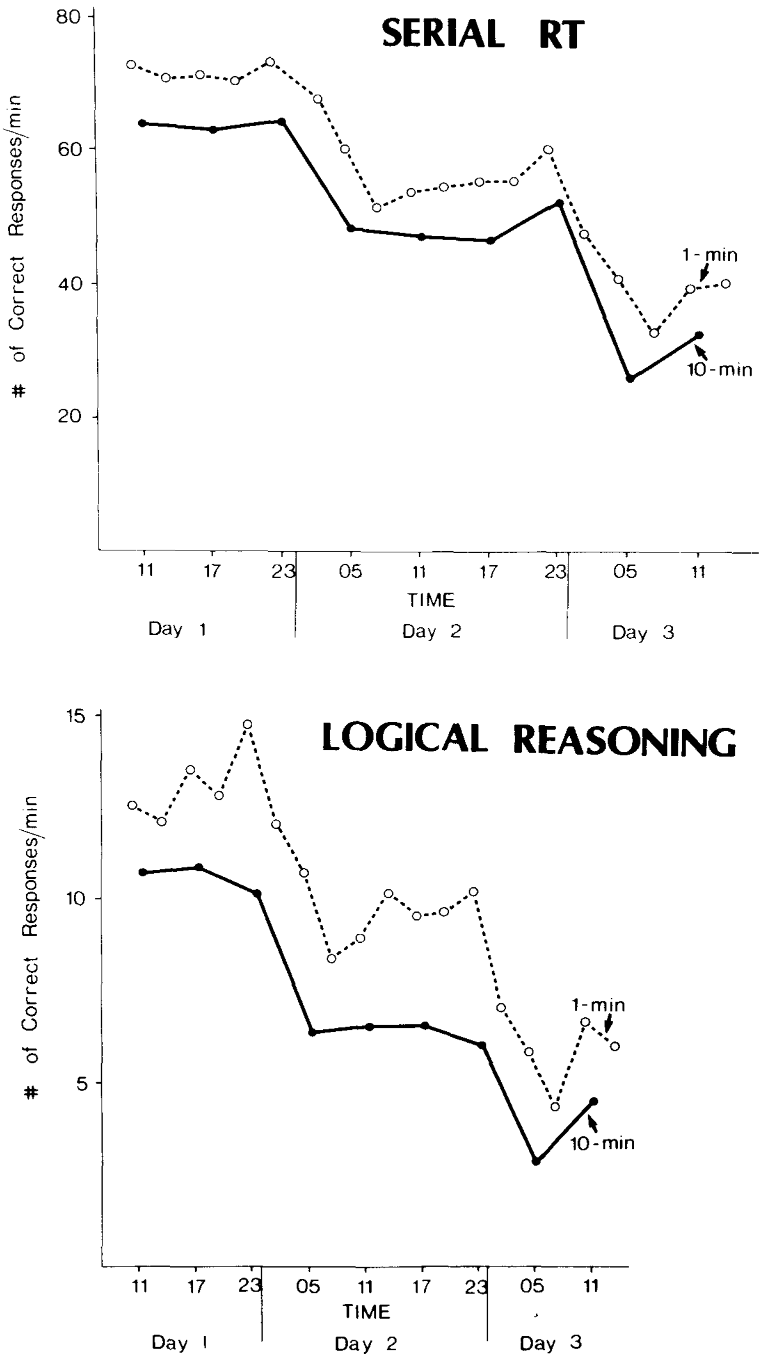


Figure 4. Performance tasks. The figure shows the topography of accurate responding for the short-duration (1-min) and long-duration (10-min) versions of the serial reaction time (upper) and logical reasoning (lower) tasks.

about 3:00 a.m. of the first night, the curves for the scales after a rest and during a work period begin to diverge and do not overlap for the remainder of the experiment.

To contrast the performance data in a similar way, the first and third trials in Sessions 1 and 3 for each of the nine experimental blocks were compared for the serial reaction time, logical reasoning, and simple and complex subtraction tasks. Figure 6 shows the superiority in accurate performance for the trials at the beginning of the work session (following a rest period) in contrast with the middle of a work session for the four tasks. As the performance data were somewhat more variable than the self-report data, because the performance data were based on a single estimate while the self-report scales inherently

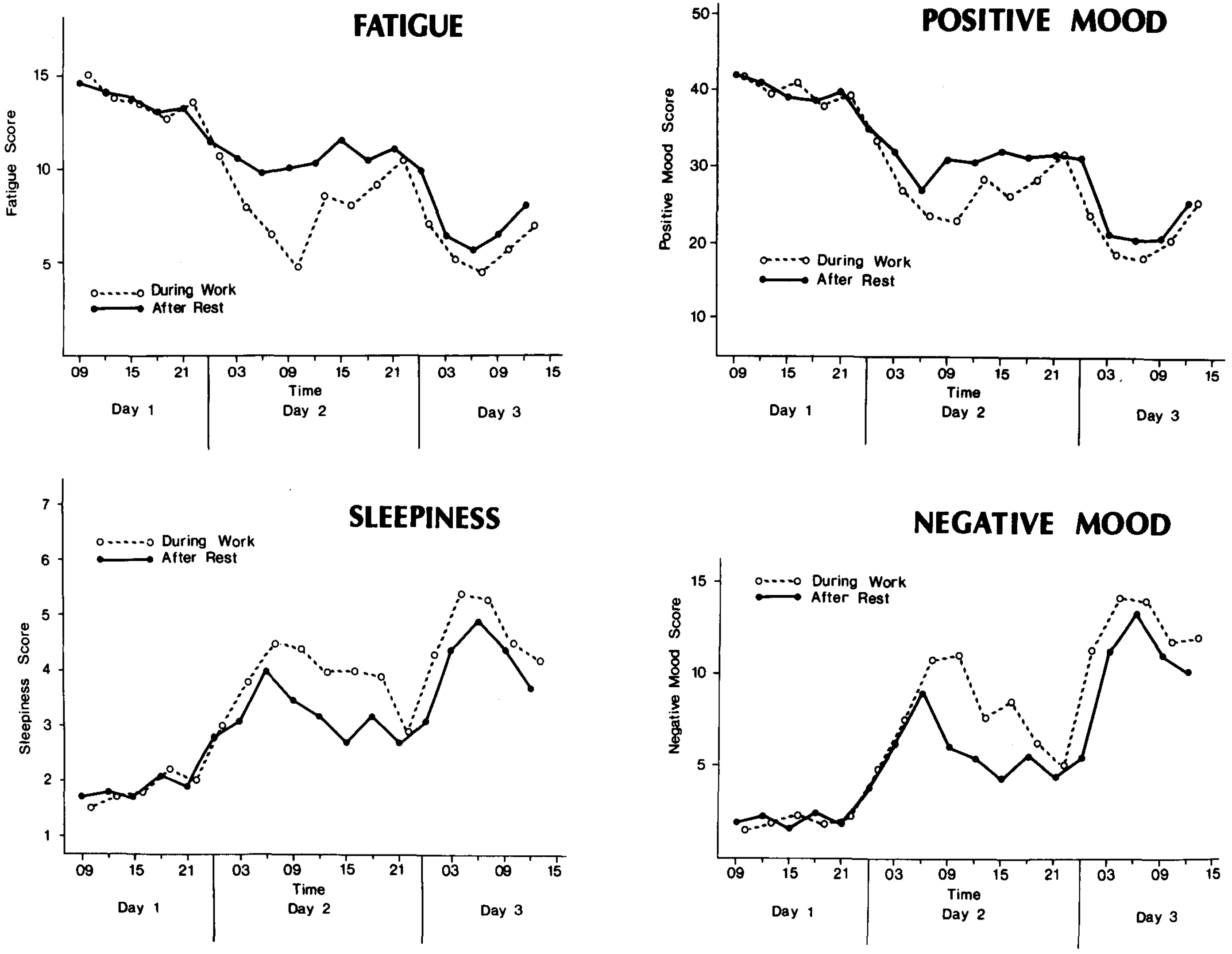


Figure 5. Self-report scales. The figure shows the differential changes in the subjective levels of fatigue, sleepiness, and positive and negative moods as a function of whether the subjects completed the scales after a short rest (solid line) or during a work session (dotted line). Larger numbers on the ordinate represent less subjective fatigue, greater subjective sleepiness, a more positive subjective mood, and a more negative subjective mood.

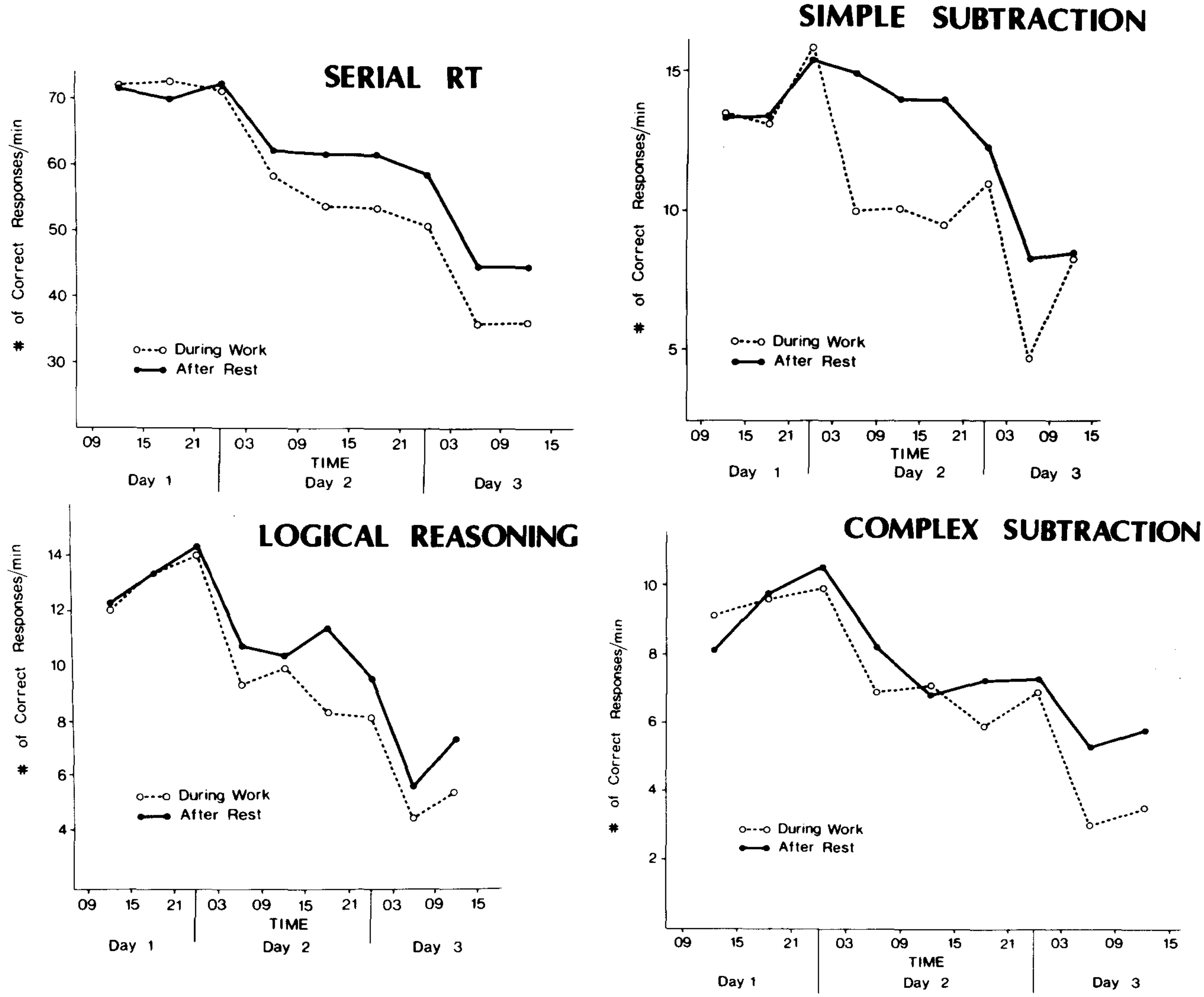


Figure 6. **Performance tasks. The figure shows the differential changes in cognitive performance over the experiment as a function of whether subjects performed after a short rest (solid line) or during a work session (dotted line). Note that once sleep-deprivation effects began to emerge, performance during a work session was significantly more impaired for all tasks in contrast to performance that followed a short rest.**

include multiple estimates of fatigue, sleepiness, and mood within each scale, the data were pooled for all subjects across both sessions of the 6-h experimental block for the analysis. Only accurate data are reported, since it was determined that there was a significant interaction of accuracy with the five trials in each session. For example, both the serial reaction time [F(4,40) = 12.12, p < .001] and the logical reasoning [F(4,40) = 3.70, p < .05] data indicated that errors remained unchanged over the session, but correct responses monotonically declined over the first four trials of the session and recovered somewhat on the final trial.

The upper left-hand panel of Figure 6 indicates that significantly more accurate serial reaction time responses occurred at the beginning of a work session than during a work session [F(1,10) = 13.26, p < .005]. This difference also interacted with time over the nine experimental blocks [F(8,80) = 3.60, p < .005] showing that greater decrements in performance occurred in the middle portions of work sessions as the experiment continued. As with the data from the self-report scales, these performance data show that the work-session location interacts with sleep-loss effects.

The lower left panel of Figure 6 shows the results from the logical reasoning task. These results were similar to those from the serial reaction time task. Performance was significantly better at the beginning of a work session than during a session [F(1,10) = 6.04, p < .05], and this difference became more pronounced as the experiment continued [F(8,80) = 2.71, p < .05]. The right side of the figure shows the data from the subtraction tasks. For simple subtraction, performance was significantly better at the beginning of a work session than during a work session [F(1,10) = 17.63, $p < .005$]. The lower right-hand panel shows the results for the complex subtraction task. These data also reveal that performance at the beginning of the work session was superior to performance during the session [F(1,10) = 10.78, $p < .01$], and this effect became greater over the course of the experiment as indicated by the interaction between this difference and the experimental blocks [F(8,80) = 4.32, $p < .01$].

DISCUSSION

Previous work on the relationship between task duration and sleep deprivation has suggested that, in order for a task to be sensitive to moderate amounts of sleep deprivation, task duration must be at least 5-10 min, and preferably 30 min to 1 h (Wilkinson, 1968). This has been considered necessary because task duration has been shown to interact with sleep loss so that sleep loss effects have emerged only during the latter portions of the task. In the present study, which differed from previous studies in that it involved more continuous and intense cognitive workloads, sleep loss and task duration effects did not interact. This interaction did not occur even though the tasks were very sensitive to both sleep loss and task duration, and different tasks showed different performance degradation profiles as a function of task duration. It did not matter whether the serial reaction time task produced a monotonic decline in performance over the entire 10 min or whether logical reasoning produced a dramatic performance decay over the first 2 min. Neither task showed an interaction between task duration and sleep loss.

The difference between our results and those of previous studies may be related to the difference in workload. Low workload may permit high levels of initial performance because of short-term high energy expenditure (Alluisi & Chiles, 1967), which may not be available when subjects are under continuous, high workload conditions. Therefore, shorter duration tasks may be more sensitive when workload conditions are more severe. In support of this hypothesis, all of the 1-min duration tasks (i.e., serial reaction time, logical reasoning, and subtraction tasks of varying difficulty) were found to be sensitive to sleep loss in this continuous, cognitively demanding environment. In addition, when comparable tasks of 1- and 10-min durations (i.e., serial reaction time and logical reasoning) were contrasted, the tasks were equally sensitive to sleep loss regardless of their duration, although the level of responding was higher for the short-duration tasks.

Another factor investigated in the present study was the location of tasks within work sessions. Using both self-report scales and short-duration performance tasks, it was found that the scales and tasks within work sessions were more sensitive to sleep-loss effects than those at the beginning of work sessions (following short rest breaks). Three related explanations may account for these differences. First, it may be that the scales and tasks occurring at the beginning of the work session showed less impairment from sleep loss because the short rest period was sufficient to allow some recovery of function. Second, it may be that the scales and tasks showed more impairment from sleep loss during work sessions because the work sessions themselves fatigued the subjects and reduced their abilities to function. Finally, the scales and tasks during work sessions may have been less obtrusive (embedded to a greater extent within the testing regimen) and less susceptible to fluctuations in motivation and fatigue than scales and tasks at the beginning of work sessions. If the latter is true, then mood and performance estimated from within work sessions may be better estimates of general levels of cognitive functioning.

Regardless of the mechanism underlying the work-session location effects, the findings imply that estimates of performance degradation based on occasional testing or tests that are placed before, or isolated from, work sessions may not be reliable or valid estimates of the performance levels that can be expected during subsequent work sessions. In order to estimate the ability of subjects to perform ongoing cognitive tasks, it appears that performance efficiency may best be estimated from tasks positioned within the ongoing behavior that the tasks are intended to index. The finding that embedded short-duration tasks were sensitive to sleep loss during high workload conditions makes the inclusion of such tasks more practical in operational settings.

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