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Effects of Sleep Deprivation on Short Duration Performance Measures Compared to the Wilkinson Auditory Vigilance Task

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Summary: The effects of one night's total sleep deprivation were examined using the Wilkinson vigilance task and four 10 min duration performance tests. A repeated measures design was used in which eight male subjects experienced one night of sleep loss, the order of sleep loss being balanced across subjects. The four short duration performance tests consisted of choice reaction time, simple reaction time, short-term memory, and a motor task, handwriting. The results confirm the effects of one night's sleep deprivation on the vigilance task and also show that performance on the two reaction time tests was significantly impaired by the loss of sleep, but not at such a high level as for the vigilance. The short-term memory test failed to show any adverse effects of sleep loss and similarly for the handwriting. The experiment shows that two portable and brief (10 min) performance tests are sensitive indices of sleep loss and should be particularly useful for assessing levels of alertness in the field. **Key Words:** Sleep deprivation—Reaction time—Vigilance—Short-term memory—Handwriting.

Over the years of sleep loss research, it has been found that certain performance tests are sensitive indices of the effects of one night's loss of sleep. The sensitivity of these tests is dependent on a number of properties present in varying proportions, depending on the nature of the task (cf. review by Wilkinson, 1965). These properties include the duration of the test, level of complexity, interest value, and the degree to which knowledge of results is available. An ideal task to show effects from loss of sleep is long, complex, uninteresting, and does not have results available to the subject.

Such tasks, for example, vigilance and serial reaction tests, have been used extensively in the laboratory setting to assess the effects of sleep loss. In a world

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where application is of the utmost importance, tests have been carried out in the field (Friedman et al., 1971; Ainsworth and Bishop, 1972). The availability of portable psychological testing equipment, with the sensitivity of the standard laboratory tests but shorter in duration, would be an obvious methodological advance.

The aim of this experiment was to use a battery of tests in which two of the tests are new pieces of portable equipment designed to be used in the field. By using this equipment in the laboratory, it was possible to compare it with a standard test, the Wilkinson Auditory Vigilance test (Wilkinson, 1970), which has been used repeatedly for sleep loss research. Two other performance tests of particular interest to sleep loss research were also included in the battery. These were a short-term memory task and a writing task.

The Stanford Sleepiness Scale (SSS) (Hoddes et al., 1972) was administered to confirm or contradict the results obtained by Hoddes et al. (1973).

METHOD

Subjects

The subjects (Ss) were eight male, paid volunteers aged 20–46 years (mean 25.5; standard deviation 8.0). They were all in good health and lacked any central nervous system drug dependency, including alcohol. No Ss had significant sleep problems or a history of disturbing symptoms following previous loss of sleep encountered in their daily lives.

The Ss were asked to abstain from alcohol and drugs at least 1 week prior to the start of the study and throughout it. No strenuous exercise, strong caffeinated stimulants, or other stimulants were taken during the study.

Procedure

A repeated measures design was used in which all Ss experienced one night of sleep loss. The experiment was based on a 5 day schedule. Days 1 and 2 (Monday and Tuesday) were practice sessions. On Tuesday night, half the Ss were sleep deprived and data following sleep deprivation were obtained on day 3. All Ss kept their normal sleep schedules on the night of day 3, the other four Ss being sleep deprived on day 4. Thus, control and sleep loss conditions were counterbalanced.

On sleep deprived day, the Ss came into the laboratory at 2100 hr and were monitored by a paid volunteer during the night until the next morning. The monitor was in continuous visual contact with the Ss; and their time was taken up with reading and organized group activities such as walking, games, and so forth. On control days the Ss had slept at home but arrived in the laboratory at 0930 ready for morning testing, which took 2 hr plus a 15 min break half way through. The schedule of tests is presented in Table 1.

The five performance tests were presented in counterbalanced order across Ss. Each subject always had the four 10 min tests presented in the same order, and each subject had the same order of testing for the four short tests as one other subject in the same group, the only difference being that the vigilance task was counterbalanced across morning and afternoon sessions for the two subjects.

TABLE 1. *Daily schedule of performance tests*

	9:30–10:30				10:45–11:45				14:30–15:30				15:45–16:45			
Group A																
S1	S	W	C	M	V	V	V	V	V	V	V	V	S	W	C	M
S2	M	C	W	S	V	V	V	V	V	V	V	V	M	C	W	S
S3	V	V	V	V	S	W	C	M	S	W	C	M	V	V	V	V
S4	V	V	V	V	M	C	W	S	M	C	W	S	V	V	V	V
Group B																
S5	W	S	M	C	V	V	V	V	V	V	V	V	W	S	M	C
S6	C	M	S	W	V	V	V	V	V	V	V	V	C	M	S	W
S7	V	V	V	V	W	S	M	C	W	S	M	C	V	V	V	V
S8	V	V	V	V	C	M	S	W	C	M	S	W	V	V	V	V

Abbreviations: V, Wilkinson's auditory vigilance task; S, simple reaction time test; C, four choice serial reaction time test; W, writing task; M, short-term memory task.

For one experimental day, group A was sleep deprived; for the other group B was sleep deprived.

The two reaction time tests were separated so that sequences such as WSCM, accounting for 12 of the possible 24 orders of presentation, were not used. Of the 12 possible combinations remaining, the design selected to provide the most adequate balance coupled the simple reaction time test (S) with the writing test (W) and the four choice serial reaction time test (C) with the short-term memory task (M). The design of presentations can be seen in Table 1.

The Ss were tested in groups of four, consisting of two sleep deprived and two non-sleep deprived Ss. The tests were repeated twice a day, the schedule being: 0930–1030, 1045–1145, lunch, 1430–1530 (avoiding, it was hoped, the post-lunch dip), and 1545–1645.

The SSS was completed every 15 min, the Ss being asked to write a number from one to seven which corresponded to their self-assessed mean level of sleepiness during the preceding 15 min period. It was completed beginning immediately after awakening until evening sleep, except during the vigilance test and during the overnight sleep deprivation period. Thus, the SSS results were also helpful in assessing the amount of sleep in the home environment. To compare SSS between sleep deprivation and base-line days, a mean of all 29 SSS values was taken symmetrically across the test period from 1 hr pretest (0830) to 1 hr posttest (1745).

During the week of the experiment (July) the room temperature ranged from 66–72°F (wet bulb) and 78–88°F (dry bulb). This warm weather had been present at least 2 weeks before the start of the experiment and was maintained throughout.

Apparatus

The performance tests consisted of the 1 hr Wilkinson auditory vigilance task and four 10 min tests.

In the 1 hr vigilance task the Ss had to listen to regularly spaced tones (500 msec), half a second in duration, occurring at intervals of 2 sec. Forty of these tones, randomly presented during the hour, were slightly shorter (400 msec) than the others. The tones were submerged in a background of high intensity (85dB) white noise.

The simple reaction time task [based on a 10 min auditory reaction time task used by Lisper and Kjellberg (1972)] was a portable cassette recording apparatus in which the stimulus was the onset of a digital millisecond clock and the response was a key press which stopped the digital clock at the reaction time. Stimulus onset of the next series of numbers occurred randomly between 1 and 10 sec after the extinction of the digital display by the previous response.

The four choice portable cassette recording apparatus (Wilkinson and Houghton, 1975) was a self-paced serial choice reaction time task consisting of four lights arranged in a square below which were four similarly arranged keys. At first a light was on and the subject responded by pressing the button corresponding geometrically to that light. Whether his response was correct or not, the light was extinguished and after 120 msec either the same light or one of the others came on, according to a random program of presentation. The cycle was then repeated.

The short-term memory test consisted of an auditory presentation of eight digits at half second intervals followed by a 6 sec delay in which to record the series on paper.

In the writing test, the Ss were required to produce a row of three items. Each page consisted of 16 rows, and there were three pages to complete in 10 min. The first item on each row was to copy a word in capital letters, the length of word ranging from four to nine letters, every word containing the letter 'O'. For the second item, the Ss had to sign their names. Finally, the Ss had to write four continuous 't's, placing the crossbar on each 't' separately afterward. Each test repetition involved the same words in pseudorandom order. Auditory clicks were used to pace each item, at 4 sec intervals. Each of the last four tests was 10 min in duration.

The SSS was completed at the end of each 15 min block in which the test occurred, apart from during the periods of the vigilance task. The comparison of subjective sleepiness to the objective tests is considered in a second report (Glenville and Broughton, in press).

RESULTS

A repeated measures analysis of variance with subjects as the between factor and a 2 × 2 crossed classification for the within factors was performed on all the data except on the SSS values (ordinal level of scaling), where the Wilcoxon matched-pairs signed-ranks test was used. The 0.05 rejection region was adopted in all the tests. The measures studied and the results are summarized in Table 2. For the auditory vigilance test, results included the signal detection parameters d′ (ability to discriminate) and β (willingness to respond) (Tanner and Swets, 1954).

The results show the effects of one night's sleep deprivation on the various performance tests. The main points of interest are the significant detrimental effects of loss of sleep on ability to discriminate (d′) and on number of hits in the vigilance task, the increase in mean reaction time in both the 10 min duration four

TABLE 2. *Effects of loss of sleep on performance variables and SSS ratings*

	VIGILANCE				
	d′	β	Hits	False positives	SSS
Control	3.4	235.6	24.9	2.7	2.7
Sleep deprived	2.4[c]	160.8	12.9[d]	4.8	5.0[b]

	SIMPLE REACTION TIME	
	Mean reaction time	SSS
Control	206.2	3.0
Sleep deprived	260.7[a]	4.9[b]

	FOUR CHOICE			
	Mean reaction time	% Errors	Gaps	SSS
Control	400.7	2.8	6.4	3.1
Sleep deprived	494.4[a]	6.1	27.6[a]	5.0[b]

	SHORT-TERM MEMORY		
	% Correct	% Strings correct	SSS
Control	95.6	83.8	3.0
Sleep deprived	95.2	84.4	5.0[b]

	WRITING				
	Area of 'O'	Area of signature	Area of 't'	Crossbar placement	SSS
Control	8.4	277.3	22.1	1.6	2.8
Sleep deprived	7.7	255.2	19.7	1.2	4.8[b]

[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.005$.
[d] $p < 0.001$.
Note: All reaction times are in milliseconds; gaps are in absolute numbers; area measures are in square millimeters; placement measures are in millimeters.

choice and simple reaction time tests, and an increase in number of gaps (responses over 1 sec) in the four choice test. It is also interesting to note that mean SSS values were significantly increased after loss of sleep in relation to all the tests.

The four choice and simple reaction time data were also analyzed with respect to time on task. A significant ($p < 0.05$) interaction was found between gaps on the four choice task and halves of the test, such that the difference between sleep loss and control conditions was greater toward the end of the test. There were no significant interactions between mean reaction time and time on task on either the four choice or simple reaction time tasks.

Using a Wilcoxon matched-pairs signed-ranks test, it was shown that a significant ($p < 0.01$) effect of sleep loss was apparent after only the first 5 min of testing.

This effect was confined to the following parameters: mean reaction time on both tests and gaps on the four choice test.

Concerning the writing task, the crossbar was measured from the left hand side of the upright, the sign being adjusted if the crossbar did not start on the left. The trend for all writing measures was for a decrease with sleep deprivation, with none of the measures reaching significance. There was a significant ($p < 0.001$) time of day effect on upright 't' height such that writing size increased in the afternoon as compared to the morning. This trend was similar for all the handwriting variables, except for the crossbar placement.

As can be seen in Table 2, there were no significant effects of loss of sleep on the short-term memory task.

There were no significant time of day effects for any of the performance measures (except upright 't' height).

Only seven Ss make up the data for the simple reaction time test, as one subject omitted to press the record button of the portable apparatus.

DISCUSSION

The results confirm the effects of one night's total sleep deprivation on the 1 hr vigilance task (Wilkinson, 1970) and, as might be expected, further confirm that it is the most sensitive task of the five used (for example, number of hits on the vigilance test are detrimentally affected by loss of sleep at the 0.001 level compared to 0.05 for the measures on the other tests).

There were significant detrimental changes on both the short 10 min tests, and they were equally sensitive. Subsequent analysis of intraindividual data showed that the simple reaction time test was significantly increased in mean reaction time, base-line versus sleep deprived in six of the seven Ss. The seventh subject also showed increased reaction times after sleep deprivation, but these were not significantly different due to a large variance. The test therefore appears to have considerable power even on individual Ss. Because of its simplicity, it was possible to examine individual reaction times for the simple reaction time test, but this was too complex for the four choice test.

The results confirm that gaps are more affected in a self-paced multiple choice task than are errors (Williams et al., 1959). It has been shown (Wilkinson and Houghton, 1975) that the four choice test of serial reaction is comparable to Leonard's five choice serial reaction apparatus (Leonard, 1959) with gaps in the former being taken as an interval of 1 sec or more elapsing between responses.

The significant interaction between gaps on the four choice test and time on task agrees with the standard findings in sleep loss research (Wilkinson, 1958) that task duration and sleep deprivation effects are closely interrelated. Task duration is an important variable in sleep loss research and it is therefore of particular interest that this interaction was present in a task lasting only 10 min.

The other important finding is that both tests (simple and four choice reaction time) were sensitive enough to allow the effects of sleep deprivation to become apparent after only 5 min of testing. In Leonard's five choice test, usually performed for 20 min, there were no differences in performance between sleep deprived and non-sleep deprived conditions in the first 5 min of testing (Wilkinson, 1958).

There were no significant effects of sleep loss on short term memory. Hamilton et al. (1972) found that Ss showed their best short-term memory performance after having only 4 hr of sleep, as compared to 6 hr, and both of these were better than 7½ hr sleep. This trend is apparent in our study, where the percentage of strings correct is highest for the sleep deprived Ss. It does not, however, reach significance, perhaps due to the fact that in our study the test lasted 10 min as compared to 30 min in the experiment conducted by Hamilton et al. Moreover, Spence and Wilkinson (1973) showed adverse changes following one night of sleep deprivation using a 30 min test. But these effects were shown to be confined mainly to the second 15 min portion of the test. It is therefore probable that short-term memory tasks should be of longer duration in order to be sensitive to loss of sleep.

The results confirm the findings of Hoddes et al. (1973) that a single night of total sleep deprivation causes a significant increase in mean SSS scores. [This aspect and the correlations between SSS scores and individual performance are treated in a second report (Glenville and Broughton, *in press*)]. Hoddes et al., however, compared the average of four base-line days to one sleep deprivation day. It would seem more reasonable to have compared the last base-line day alone to the sleep deprived day. Moreover, in their study there was no order control for the sleep deprivation.

One very interesting finding is that, although the simple reaction time test gives the Ss knowledge of results, it does not abolish the effects of sleep loss as occurs for knowledge of results in the experiment by Wilkinson (1961). This may be due to the fact that in the latter study the experimenter actually conveyed the results to the Ss, whereas in our study the Ss had to formulate for themselves how well they were doing, from noting the visible reaction time figures. This latter situation is similar to that in the experiment by Williams et al. (1959) where again knowledge of results did not reduce the effects of loss of sleep.

Although it may be noted that the room temperature was unusually high for England, it is unlikely that temperature has had a major effect. This is because the same heat wave existed for both base-line and sleep deprived conditions, which were counterbalanced throughout the period. It is possible, however, that heat made the subjects more sensitive to sleep deprivation than they otherwise would have been as an interactive effect.

It appears that one night's sleep deprivation produces a tendency to write smaller. None of the main measures reached significance, but this may be due, at least in part, to the large human measurement error involved.

The two short duration reaction time tests have also been used in the field to assess the effects of a combination of night shift and loss of sleep (Glenville and Wilkinson, *in press*) and were found to be sensitive measures of the two stresses.

In conclusion, the results indicate that the portable simple reaction time and serial four choice tests, using brief testing procedures which should not interfere seriously with work schedules, can give significant reductions in performance after one night's sleep loss.

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