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AFTEREFFECT OF SLEEP DEPRIVATION[1]

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24 enlisted men stayed awake one night, slept normally the next, and on the following day carried out either a 1-hr. vigilance task (Experiment I, 12 Ss) or a 30-min. test of serial reaction (Experiment II, 12 Ss). In each case performance fell below control levels (normal sleep on both nights). Ss were their own controls in a balanced design. This "aftereffect" of sleep deprivation was greatest in the morning and, unlike the direct effect of sleep deprivation, was apparent at the start of the test and increased little with time. This suggests disturbed diurnal rhythm as the cause rather than failure to make up for lost sleep.

Almost without exception studies of loss of sleep have been concerned primarily with the "direct effect" of sleep deprivation, that is with the changes which occur during the actual period of sleeplessness. Occasionally, however, measurements have been continued into the periods of recovery following restorative sleep in an attempt to assess what may be called the "aftereffect" of sleep deprivation. These additional measurements are valuable as the only evidence we have so far of this aftereffect, but the conclusions which have emerged are rather contradictory. This is understandable, for such dual-purpose experiments may make it difficult to achieve the necessary experimental control for measuring what may be a relatively small effect. The aim of the present study has been to achieve such control by making the measurement of the aftereffect the main objective. Specifically the question was whether any of the known effects of one night's loss of sleep on visual vigilance (Wilkinson, 1960) and on choice serial reaction (Wilkinson, 1961b) remained after one night of restorative sleep.

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METHOD

Tests.—The vigilance test used in Exp. I has been described fully elsewhere (Wilkinson, 1961a). The *S*s watched a screen 6 in. in diameter at a distance of about 2 ft. At an average interval of 3 sec. the screen was faintly illuminated for $\frac{1}{2}$ sec. Occasionally there would be a dim spot of light present in any of 10 possible positions irregularly distributed about the screen. The *S* had to watch for this signal and report its presence by pressing a key. He watched continuously for 1 hr. during which the screen lit 1,200 times. On 32 of these occasions, irregularly spread in time, the signal was present. Continuous "white" noise at 65 db. was used to mask extraneous sound as *S* worked alone in a cubicle.

In Exp. II the test was one of choice serial reaction, Leonard's 5 Choice Test (Leonard, 1959). The *S* is faced with five lights and five associated metal contacts; at the outset one of the lights is on; *S* touches the appropriate contact which puts it out and brings another on; again the associated contact is touched, and so the cycle continues with *S* working at his own speed for 30 min. The order in which the lights come on appears random. Scores are in terms of the number of correct taps, the number of errors (when an incorrect contact is touched, the light still moving on), and finally the number of gaps, i.e., periods of 1½ sec. elapsing between successive responses.

Subjects.—Twelve *S*s were used in Exp. I and a further 12 in Exp. II. They were enlisted men between the ages of 18 and 30, and all were volunteers to undergo sleep deprivation.

Sleep deprivation.—This involved staying awake under supervision from 7 A.M. on Monday morning until about 5 P.M. Tuesday, that is around 34 hr. During the sleepless night *S*s amused themselves in their recreation room. The next day was spent in tests of another nature and in routine duties (Exp. I) or in the same test of serial reaction and routine duties (Exp. II). After this *S*s were free to sleep until called at the usual time of 6.30 A.M. the following morning, a period of some 13 hr. No *S* slept all of this time; the usual practice was to sleep for 2 hr. in the late afternoon and then remain awake until about 11 P.M., the normal time for retiring. On the following day, Wednesday, they were tested. This is called the Aftereffect condition. For the control tests (Normal condition) the program was just the same except that *S*s slept quite normally, that is on the Monday as well as on the Tuesday night.

Design.—In Exp. I *S*s were tested four times on four successive Wednesdays; 6 *S*s were tested in the morning and the other 6 in the afternoon. The *S*s of Exp. II were tested on two Wednesdays (separated by 4 wk.); each *S* was tested both in the morning and the afternoon of each Wednesday. This design and distribution of the conditions for both experiments are shown in Table 1.

Results

Wilcoxon's (1949) nonparametric test was used to calculate the significance levels shown in this section. The influence of the aftereffect of sleep deprivation was seen most clearly in the vigilance test of Exp. I where it reduced the total number of signals reported by about one fifth (Table 2). Out of 12 *S*s 9 showed this effect, 2 showed no change, and only 1 showed a slight opposite tendency, $t(9) = 1$, $p < .01$. The aftereffect of loss of sleep impaired performance at least as much in the first half of the test, $t(10) = 0$, $p < .001$, as in the second, $t(11) = 15.5$, $p < .1$. This is in marked contrast to the direct effect of loss of sleep, which is absent early in the test but increases with time spent at work (Wilkinson, 1960). The aftereffect was greater among the 6 *S*s tested in the morning than in the 6 tested in the afternoon, although this trend was insignificant.

The results in the test of serial reaction used in Exp. II are in the same direction as those in vigilance but not so well defined (Table 3). The aftereffect reduced the total number of corrects and also the total

TABLE 1

Experimental Designs of the Two Experiments

Exp. I	Day 1	Day 2	Day 3	Day 4
6 *S*s	Aftereffect	Normal	Aftereffect	Normal
6 *S*s	Normal	Aftereffect	Normal	Aftereffect
Exp. II	Day 1		Day 2	
	A.M.	P.M.	A.M.	P.M.
6 *S*s	Aftereffect	Aftereffect	Normal	Normal
6 *S*s	Normal	Normal	Aftereffect	Aftereffect

Note.—Aftereffect = normal sleep the night before but no sleep the night before that. Normal = normal sleep on both previous nights but otherwise the same routine.
The days were separated by 1 wk. in Exp. I and 4 wk. in Exp. II.

TABLE 2

AVERAGE SIGNALS SEEN PER *S* IN VIGILANCE

	Normal Sleep	Aftereffect of No Sleep
1st half of the test	10.0	8.0
2nd half of the test	8.3	6.9
Whole test	18.3	14.9

errors. These trends did not reach significance but, so far as they go, they suggest that the aftereffect caused *S*s to trade speed for accuracy. The clearest influence of the aftereffect appeared in gaps, (periods of $1\frac{1}{2}$ sec. during which *S* failed to respond) which is the measure which also shows the greatest direct effect of sleep deprivation. In the morning tests significantly more gaps were recorded under the aftereffect than in the tests under normal sleep, $t(11) = 13$, $p < .05$. In the afternoon tests this effect was reduced to very little. It will be recalled that a similar diurnal trend was observed in Exp. I. As in the first experiment also, the aftereffect was at least as marked in the first half of the test (when 10 out of 12 *S*s showed it during the morning tests) as in the second half.

TABLE 3

AVERAGE SCORES IN THE FIVE-CHOICE TEST OF SERIAL REACTION

	Morning		Afternoon	
	Normal Sleep	After-effect of No Sleep	Normal Sleep	After-effect of No Sleep
Gaps				
1st half	10.2	17.2	13.3	17.2
2nd half	17.8	24.4	25.4	25.0
Total	28.0	41.6	38.7	42.2
Corrects				
1st half	1464	1419	1502	1442
2nd half	1427	1405	1442	1411
Total	2891	2824	2944	2853
Errors				
1st half	31.0	26.2	35.4	26.9
2nd half	33.8	23.5	35.2	29.6
Total	64.8	49.7	70.6	56.5

DISCUSSION

Previous attempts to assess the aftereffect of sleep deprivation have produced contradictory conclusions. Three studies reported an adverse aftereffect on the day following the sleep which terminated the period of deprivation (Edwards, 1941; Smith, 1916; Williams, Granda, Jones, Lubin, & Armington, 1962). Three others reported no effect (Robinson & Hermann, 1922; Robinson & Richardson-Robinson, 1922; Tyler, 1955), and a further three authors remained noncommittal (Armington & Mitnick, 1959; Williams & Lubin, 1959; Williams, Lubin, & Goodnow, 1959). In none of these reports, however, were any significance levels ascribed to the results, and, in general the experimental designs were unsatisfactory. This was due mainly to the assessment of the aftereffect being a secondary objective in experiments whose main aim was to measure the direct effect of loss of sleep. In particular it was difficult to distinguish a true aftereffect from the influence of repeated testing on the same test. This factor can either improve performance through learning, or, as is more likely with tests which are vulnerable to loss of sleep, impair performance due to the declining novelty of the experimental situation (Wilkinson, 1961b). When the same *S*s are repeatedly exposed to a test before, during, and after a period of sleep deprivation such influences make comparisons of pre- and postdeprivation performance tenuous; and even if a separate group is used having the same program of tests but no sleep deprivation this may be unsuitable as a control because of differential practice effects with and without sleep. One solution, that of the present Exp. I, is to omit measurement altogether during the period of deprivation itself. A second (Exp. II) is to use *S*s as their own controls but to counterbalance the order of the experimental and control tests in order to achieve a better balance of the effects of practice. With these precautions the present study has shown in two independent experiments that two tasks known to be particularly sensitive to the direct effects of sleep deprivation are still impaired on the day following restorative sleep. This allows us to say with some confidence that a normal night's sleep does not restore the moderately sleep deprived man to normal.

Still in doubt, however, are the reasons for this. If the body's resources are depleted in some way by prolonged waking activity it may be that additional sleep is essential to restore them to normal by the following day. On the other hand our observed aftereffect could be due to the disruption of diurnal physiological rhythms by sleep deprivation, as Kleitman (1939) found in the case of body temperature. The latter explanation is preferred because of two features of the present results. The first is the suggestion in both experiments that the adverse influence of the aftereffect is less in the afternoon than in the morning. No sleep was taken in the interval and so the best explanation may be that normal physiological rhythms were disturbed in the morning, due perhaps to deeper or more prolonged restorative sleep the night before, and had become partially re-established by the afternoon.

Secondly, it is interesting that the *way* in which performance was impaired by the aftereffect was unlike that of the direct effect of sleep deprivation. Instead of developing gradually with time spent on the test the aftereffect was apparent early in the test and changed little as the test wore on. There is some evidence that changes in performance due to diurnal rhythm per se have this characteristic (Colquhoun, 1962), and this further reinforces the impression that these influences were the main cause of the aftereffect of sleep deprivation we have observed. It may be that when sleep has been lost an aftereffect is best avoided, not by taking additional sleep, but by resuming normal routines as quickly as possible.

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