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Key terms: adrenaline excretion; body temperature; circadian rhythm; follow-up field study; follow-up study; long-term adjustment; nighttime work; psychophysiological activation; reaction time; rotating shift work; rotating shift worker; self-rated activation; shift work; shift worker; short-term adjustment; temporal pattern

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Temporal patterns in psychophysiological activation in rotating shift workers — A follow-up field study one year after an increase in nighttime work

by Kerstin Dahlgren, PhD [1]

DAHLGREN K. Temporal patterns in psychophysiological activation in rotating shift workers — A follow-up field study one year after an increase in nighttime work. *Scand j work environ health* 7 (1981) 131—140. The study concerned the long-term effects of a weekly rotating day-night shift schedule on circadian functions. It was performed 1 a after the introduction of an increase in nighttime work and was a follow-up of a study performed one month after the change in workhours. Fourteen male typesetters were observed in connection with the first, fourth and seventh night-shifts of the "night week" and the two dayshifts of the "day week." Measurements were taken of body temperature and self-rated activation during awake periods, of adrenaline excretion during work and sleep, and of choice-reaction time during work. The results showed that a different pattern of variation in circadian functions was present 1 a after the increase in nighttime work when compared to the pattern one month after the increase. The change in pattern consisted mainly of a general flattening of the curves during both day and night work, although some changes from the beginning to the end of the nightshift week could still be noticed.

Key terms: adrenaline excretion, body temperature, circadian rhythms, reaction time, rotating shift work, self-rated activation, short- and long-term adjustment.

There are many different types of shift-work schedules prevalent in today's industry, continuous shift systems allowing for the greatest variation in shift schedule arrangements. Only in recent years, however, has any substantial research been devoted to the problem of how shift systems should be arranged in order to minimize the negative psychophysiological consequences associated particularly with night work. These consequences mainly result from a disruption of the temporal organization of various physiological and psychological functions, and they are considered a potential risk to health and well-being. Thus, when the relative merits of different types of shift schedules are compared from a psychophysiological point of view, one of the main considerations is the degree to which so-called circadian (ie, approximately 24 h) rhythms can be adjusted to the alternations in the hours of work and sleep. Of particular relevance are the circadian variations in the general arousal level, ie, in both physiological and psychological indices of activation. The present investigation concerns the degree of circadian adjustment achieved in connection with a rotating shiftwork schedule and, more specifically, the long-term effects of this type of schedule on circadian functions.

Although many of the circadian rhythms have been shown to be of endogenous origin [see, for example, the review by Conroy & Mills (6)], they can be shifted in phase when *all* important time cues in the environment, usually referred to as "Zeit-

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geber" or "synchronizers," are also shifted. This is the case, for example, in connection with rapid transzonal air travel, where adjustment for most functions develops within a week (12). Night work, on the other hand, represents a situation in which only the waking and sleeping times are phase shifted and many of the important synchronizers remain intact. In this case the circadian system is under the influence of conflicting synchronizers, rendering complete adjustment to the nightshift more difficult.

Experimental studies of continuous night work performed in the laboratory have allowed for well-controlled observations of day-to-day trends in the adjustment of rhythms, body temperature being the most studied function (4, 5, 13). It should, however, be pointed out that in the laboratory the influence of conflicting synchronizers is reduced due to the limited contacts with the social environment. In one experimental study (13) of three consecutive weeks of night work, where the social isolation of the subjects was minimized, the major change in the body temperature rhythm occurred within the first week. It took the form of a partial adjustment of the rhythm, the temperature minimum shifting phase towards the sleeping period and the phase position of the maximum remaining almost unchanged.

These changes in circadian rhythm within a period of successive nightshifts illustrate what has been called short-term adjustment. Among experienced shift workers it is, however, possible that an increase in the speed of short-term adjustment will develop as a function of their experience with the shift schedule. This change in the speed of short-term adjustment has been referred to as long-term adjustment. It was first illustrated in an experimental field study in which three workers changed over to night work for a period of 13 weeks (14). During the 5 d of night work each week body temperature was recorded at 4-h intervals. In one of the subjects there was evidence of a long-term adjustment in that the time taken to achieve "the definite night shift curve," which was a flattening of the body temperature rhythm, progressively decreased each week. In experienced permanent night workers, with a continuous shift schedule of six nights and three off days, a fairly good adjustment has been found already on the first day after off days with regard to adrenaline excretion, body temperature, and self-rated activation (16).

It is unclear whether any long-term adjustment to night work develops in schedules of rotating shift work. Most of the performed studies have been of a transverse character, lacking relevant comparison groups, while the most relevant method would be to follow circadian functions for a sufficient length of time after introduction to a particular rotating shift schedule.

In the present investigation a group of rotating shift workers alternating between a day and night week were studied. This group was first studied one month after a change in work hours during the night shift week (2), which involved an increase in the amount of nighttime work. The results of this first study indicated a short-term adjustment during the nightshift week with regard to oral temperature, subjective alertness, and adrenaline excretion. This adjustment took the form of an increase of levels during night work from the beginning to the end of the nightshift week. The purpose of the present investigation was to study the long-term effects of this rotating shiftwork schedule on circadian functions through a follow-up study 1 a after the first investigation.

Methods

Subjects and general design

The subjects consisted of 14 male typesetters employed in the printing department of a large Swedish newspaper. Nine out the 13 members in the first study were able to participate in the present study, while five subjects were "new." These new subjects had, however, worked on this shift schedule for the same length of time, but were on vacation at the time of the first study. Since separate analyses of results for old and new members revealed very similar results, they have been combined into one group in the following summary of results. The median age for this group was 43 a with a range of 26—59 a.

The subjects' shift schedule consisted of seven consecutive nights of work between approximately 2230 and 0500, followed by one free day, two days of work between 0730 and 1630 and four free days. Thus, they alternated between a night-oriented and a day-oriented week, although the latter contained less actual work. At the time of the present study all the subjects had been on this schedule for 1 a in comparison to only one month in the first investigation. Their earlier shift schedule differed from the present with regard to the amount of nighttime work during the nightshift week, ie, they previously worked five late evenings between 1830 and 0230 and two nights between 2300 and 0600. Their median experience with that system was 4 a.

The general design was identical to the first investigation with the exception that also the first workday of the day week was included. Thus the subjects participated in the investigation on the first, fourth, and seventh days of the nightshift week and on both days of work in the day week. Measurements of physiological and psychological functions were also carried out at the same clock hours as in the first study, and they have been described in connection with each variable.

Physiological variables

Oral temperature was measured with a standard hospital thermometer inserted sublingually for 4 min. In connection with night work the measurements were made when the subjects arose and at 1600, 2000, 2400, 0200, 0400 and before sleep. During day work, the measurements were started when the subjects arose and were repeated at 0900, 1200, 1500, 2000 and at bedtime.

The urinary excretion of catecholamines was measured during night work for four time periods of approximately 2 h each and also for the whole sleeping period following the nightshift. Thus, the subjects emptied their bladder at 2000, and then urine samples were collected at 2230, 0100, 0300, and 0500. Before going to sleep, the subjects again emptied their bladder, and they collected a urine sample themselves at home after rising. During day work catecholamines were measured for four time periods and for the sleeping period preceding work. Thus urine samples were collected by the subjects themselves upon rising and then at 0730, 1030, 1330, and 1630. All the samples were adjusted to a pH of about 3, the urine volume was measured, and smaller samples were stored at $-18^{\circ}C$ until analyzed according to the method of Andersson et al (3), which is a semiautomated version of the original fluorimetric technique developed by Euler & Lishajko (7).

Self-rated activation

The general activation factor translated from Thayer's Activation-Deactivation Adjective Checklist (17) was used for rating alertness. Adjectives were rated from "not at all discriptive" to "completely descriptive," and the ratings were scored from one to four. The ratings were made simultaneously with the measurements of body temperature.

Performance test

A visual choice-reaction time test was used as a measure of performance at 2400, 0200, and 0400 during night work while during day work the performance sessions took place at 0900, 1200, and 1500. The stimuli consisted of three yellow light signals placed at one end of a rectangular plate. A rest key was situated at the end nearest the subject. The light signals were presented automatically in random order with intervals varying between 3 and 7 s. The subjects were instructed to press the key corresponding to the light signal presented. Reaction time was recorded by an electronic computer with an accuracy of 1/100 s. The first five recordings were regarded as practice and were discarded. Altogether 75 signals were presented during each trial, and the whole test period took around 10 min.

Questionnaire

A questionnaire was used to collect information on diurnal type, problems in adjusting to shift work, job satisfaction, psychosomatic symptoms, and background data.

Statistical methods

For a determination of whether a parameter exhibited a significant variation with time of day, data were subjected to a one-factor analysis of variance for repeated measurements according to Winer (18). This analysis was performed separately for each day of measurement. Furthermore, each parameter was subjected to a two-factor analysis of variance for repeated measurements (18) to test the change during the nightshift week, the factors being "time of day" and "days."

Results

Physiological variables

The body temperature curves for the night- and dayshifts are shown in fig 1. The analyses of variance revealed significant variations in temperature with time of day in connection with the first and last nightshifts and also during both dayshifts (table 1). On the whole, the temperature curves during the nightshift week lacked a pronounced variation. There were however a few changes in the characteristics of the curves from the beginning to the end of the week. In connection with the first nightshift a small peak was present outside workhours at 2000, and there was also a significant variation over time. In the middle of the nightshift week there was a decrease in average temperature outside the workhours and a small increase during work that resulted in a flattening of the curve and a nonsignificant variation over time. During the last nightshift a more pro-

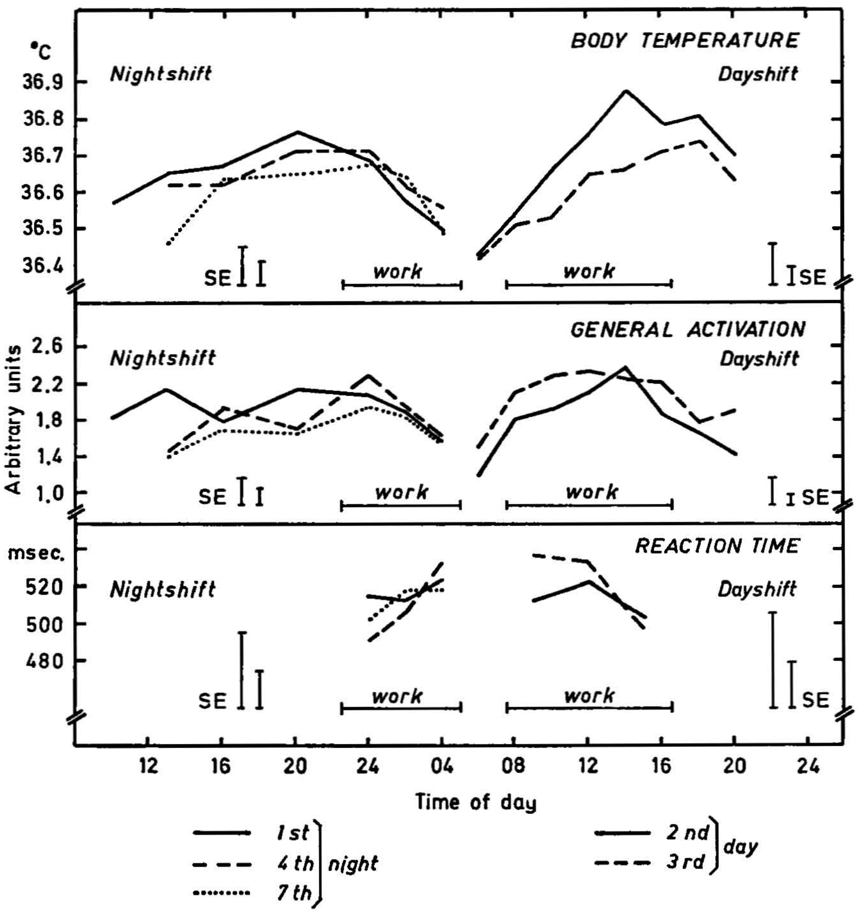

Fig 1. Mean values and range of standard errors (SE) for oral temperature, self-rated activation, and choice-reaction time in connection with the first, fourth, and seventh nightshifts and the two dayshifts in the day week.

nounced and significant variation was found, with low levels upon rising and before sleep. From the beginning to the end of the nightshift week there was a slight shift of the highest levels towards the workhours, but the changes in pattern of variation were not significant. The temperature variations during the dayshifts were characterized by a relatively slow rise during the day, particularly on the second dayshift, for which the average levels were similar to those during nightshift work.

The average level of adrenaline excretion during work and sleep in connection with night and day work is shown in fig 2. These results should, however, be interpreted with caution, since, during the process of urine analysis, a technical fault appeared. Most of the samples could be reanalyzed, but in some cases the urine volumes were very small. Because adrenaline excretion is of particular interest, these somewhat uncertain results have still been presented. The analyses of variance for the night- and dayshifts revealed a significant variation only during the fourth nightshift. In the beginning of the nightshift week the level of excretion during work was very low and was similar to the level during sleep. There was a tendency for the levels to increase during work towards the end of the nightshift week, but these differences were not significant. During day work the excretion levels were somewhat higher, but they lacked a more pronounced and significant variation.

Table 1. Summary of the one-factor analyses of variance for repeated measurements (time of day effect) of body temperature, adrenaline excretion, self-rated activation, and reaction time.

Variable	F-ratio	df
Body temperature		
1st night	2.3 *	6
4th night	1.7	5
7th night	3.2 *	5
2nd day	5.2 ***	7
3rd day	4.3 ***	7
Adrenaline excretion		
1st night	0.9	3
4th night	3.5 *	3
7th night	0.9	3
2nd day	1.5	3
3rd day	1.4	3
Self-rated activation		
1st night	1.9	6
4th night	3.2 *	5
7th night	2.1	5
2nd day	6.2 ***	7
3rd day	2.6 *	7
Reaction time		
1st night	0.1	2
4th night	2.7	2
7th night	0.4	2
2nd day	0.4	2
3rd day	1.1	2

* $p < 0.05$, *** $p < 0.001$.

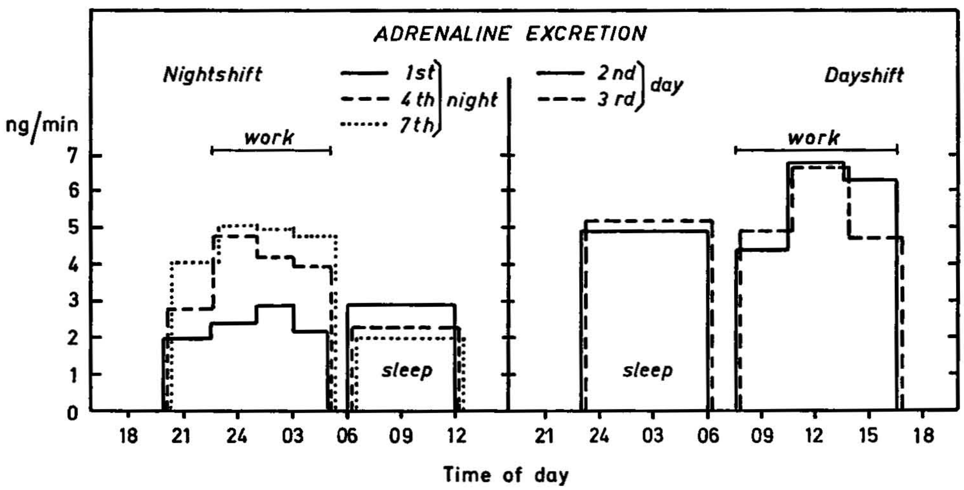

Fig 2. Mean values and range of standard errors (SE) for adrenaline excretion during work and sleep in connection with the first, fourth, and seventh nightshifts and the two dayshifts in the day week.

Self-rated activation

The average self-ratings of activation in connection with the night- and dayshifts are shown in fig 1. Significant variations with time of day were found only for the fourth nightshift and during the dayshifts (table 1). In the beginning of the nightshift week the variation was small, and no clear peak was found, whereas in the middle activation fluctuated more during the waking period, one peak appearing during work at 2400. During the last nightshift the general level of activation was somewhat lower with very small variations, although the highest levels occurred during work. No significant changes during the week were found. For the two dayshifts variations were more pronounced, and the highest levels occurred within the work periods.

Performance

The average reaction times during night and day work are illustrated in fig 1. No significant variation over time was found for the night- or dayshifts. Reaction times were somewhat shorter at 2400 on the fourth nightshift in comparison to the other shifts, but there were no significant changes during the week. Average reaction times during day work were similar or even somewhat longer than during night work.

Questionnaire

The answers on selected items from the questionnaire are summarized in table 2, where the percentages in parentheses represent their answers in connection with the first study. On the whole, the response tendencies were similar to those in the first study, although somewhat more marked. The shift workers still preferred their present workhours to day work. They also experienced more difficulties in the change from the night to day week than from the day to night week with regard to sleep and mood. They also required more days to feel adjusted during the day week than during the night week. In this follow-up study items concerning free time were also included. With regard to the experienced possibility to make use of free time, the response tendencies were completely opposite for the night and day weeks. Whereas a marked increase in the possibility to utilize free time was experienced while going from the day to the night week, a marked decrease was experienced from the night to the day week. This finding was also supported in their answers to an open question on what they usually did and how they felt during their free time in connection with night and day work. The majority were more actively engaged in various hobbies, etc, and were in a better mood during their free time after a nightshift than after a dayshift.

Discussion

Circadian functions during the nightshift week

When the results of this follow-up study are compared with those of the first study (2), performed 1 a earlier, a clearly different pattern of variation in circadian functions is seen. It consists mainly in a general flattening of the curves, although some changes from the beginning to the end of the week can still be noticed.

In connection with the first nightshift all functions showed relatively low levels during the workhours. The only significant variation with time of day was in oral temperature, but the highest levels were reached before work. The same results were found also in the first study with regard to body temperature and self-rated activation, but the variations were, on the whole, more pronounced at the time of that study. The pattern of adrenaline excretion was similar in the two studies, the low levels during work being almost equal to the sleep values, but since the whole awake period was not included, it is difficult to know whether a general flattening had occurred after 1 a.

In the middle of the nightshift week signs of adjustment appeared for all functions, mainly in a form which indicates a shift of the phase of the rhythms with the highest levels occurring in the first third of the work period. Adrenaline excretion and self-rated activation varied significantly over time with midnight peaks, which also coincided with the best performance.

At the end of the nightshift week there

was a lowering of the average level of temperature and self-rated activation. Body temperature did however show a more pronounced and significant variation over time, which was mainly due to a markedly lower level when the subject awakened.

Table 2. Frequencies of selected items from the questionnaire (translated from Swedish). The frequencies in parentheses represent the results from the study performed 1 a earlier.

Question	Response	Frequency (%)	
Would you like to change to day work rather than retain your present workhours (without change of tasks)?	Absolutely not	85	(62)
	Rather not	15	(30)
	Rather	—	(8)
	Very much	—	(—)
How do you percieve the change from the *day to night week?*	Very difficult	23	(31)
	Difficult	23	(23)
	Rather easy	31	(23)
	Easy	23	(23)
After how many days on the *nightshift* do you feel you have adjusted to the new hours?	Median = 2 d		(2)
What changes do you experience going from the *day to night week?*			
Difficulties falling asleep	Increase	50	(46)
	No change	10	(18)
	Decrease	40	(36)
Bad quality of sleep	Increase	50	(64)
	No change	8	(18)
	Decrease	42	(18)
Fatigue	Increase	59	(55)
	No change	8	(9)
	Decrease	33	(36)
Irritation	Increase	36	(55)
	No change	9	(9)
	Decrease	55	(36)
Use of free time	Increase	75	
	No change	—	
	Decrease	25	
How do you percieve the change from the *night to day week?*	Very difficult	70	(54)
	Difficult	23	(23)
	Rather easy	—	(15)
	Easy	7	(8)
After how many days on the *dayshift* do you feel you have adjusted to the new hours?	Median = 4 d		(4)
What changes do you experience going from the *night to day week?*			
Difficulties falling asleep	Increase	91	(83)
	No change	—	(—)
	Decrease	9	(17)
Bad quality of sleep	Increase	83	(83)
	No change	—	(—)
	Decrease	17	(17)
Fatigue	Increase	83	(75)
	No change	—	(—)
	Decrease	17	(25)
Irritation	Increase	55	(58)
	No change	9	(17)
	Decrease	36	(25)
Use of free time	Increase	27	
	No change	—	
	Decrease	73	

This could be an indication of a lowering of temperature during sleep. There was a tendency for adrenaline excretion during sleep to decrease from the beginning to the end of the week, but this change was not significant. In contrast to the decrease in self-rated activation towards the end of the nightshift week adrenaline excretion remained at a high level. This finding is difficult to interpret in light of the fact that adrenaline excretion has been shown to reflect subjective and behavioral activation (9). On the other hand, the same phenomenon has occurred in other studies in which subjects have also worked during their "normal" hours of sleep (1, 11), and it could be an indication of a reaction to the discomfort and extra efforts involved in maintaining work at these hours.

Circadian adjustment during the dayshifts

The pattern of variation in circadian functions differed from that found in the earlier study also with regard to the day shifts. For oral temperature this difference was in the form of a lower average level, and, although the variation over time was significant, it was characterized by a markedly slower rise during the day, particularly for the second dayshift, the highest levels of which were similar to those during night work. The levels of adrenaline excretion during sleep were relatively high, particularly in comparison to those of the first study, and no significant variation over time was found. In contrast to the first study, self-rated activation showed a more pronounced and significant variation. However, the highest levels were similar in the two studies, and the difference occurred mainly in lower levels after the subjects awoke and before they went to sleep. This result could mean that the subjects in this study were more tired upon awakening and needed more time to become fully alert and that they tired earlier in the evening.

Long- and short-term adjustment

In the first study, performed one month after the change in workhours during the nightshift, some short-term adjustment during the week could be seen in the form of an increase of the highest levels of temperature, self-rated activation, and adrenaline excretion and a phase shift of the maximum levels towards the first third of the work period. After 1 a of experience with the new shift schedule the curves had, on the whole, flattened, and, although there were still signs of short-term adjustment, the finding differed from that of the first study. The definition of the concept of long-term adjustment needs therefore to include not only time but also quality. In other words not only might there be an increase in the speed of short-term adjustment, but the short-term adjustment may also take another form.

It is thus clear that long-term adjustment to night work had occurred after 1 a on the new shift schedule, but that this adjustment had taken the form of a general flattening instead of an increase in short-term adjustment. Tendencies towards short-term adjustment during the nightshift week were however also present, indicating a slight phase shift, but with lower average levels for some functions.

The difference in adjustment during the nightshift week found one month and one year after the change in workhours could be interpreted in two ways. It could either be an illustration of the course of adjustment of circadian functions to this kind of phase shift in workhours, ie, first a smaller phase shift of rhythms and, after 1 a, a general flattening, or an indication that the pattern found after one month was more a trace of adjustment to the previous "late evening" shift and not mainly adjustment to the new workhours. One month after the change the subjects had actually worked only a total of two nightshift weeks.

Adjustment during the dayshifts was also characterized by a general flattening when compared to that of the first study. The fact that the rhythms during day work did not immediately return to a "normal" daytime variation could mean that the "partial adjustment" (flattening) found during the nightshifts represent a true entrainment of the endogenous rhythms to night work. [See, eg, Mills et al (15).] Their answers to several questions in the questionnaire also indicated that they experienced the switch to day work as more difficult than the switch to night work. This could be an indication of their being more night-oriented in their adjustment, but it should also be noted that there was a qualitative difference between night and day work in that their supervisors and many of their co-workers on the dayshift were permanent day workers. This situation could have made their incomplete adjustment more apparent by comparison.

Characteristics of the shift schedule

In this schedule an equal amount of day- and night-oriented activity was included in the shift cycle, although the day-oriented week contained less actual work. This situation resulted in partial adjustment to night work, which also had an effect on the day-oriented part. The characteristics of the adjustment during the nightshifts with regard to temperature were similar to those found in a study of full-time (4 nights/week) night nurses (8), ie, signs of a flattened rhythm in connection with the first night shift followed by a shift in the phase of the rhythm, but with a reduction in the mean level. The full-time night nurses were compared with part-time night nurses (2 nights/week) who showed no signs of adjustment. This latter type of schedule is somewhat similar to rotating three-shift work in the sense that the nightshift period usually constitutes a relatively minor part of the whole shift schedule. On the other hand, when a three-shift schedule consists of longer periods of successive nightshifts, signs of short-term adjustment have been found. Such adjustment was shown in a field study where continuous three-shift workers, with six consecutive nightshifts, had higher levels of adrenaline excretion and lower ratings of fatigue on the last night in comparison with the first (10). When night-oriented activity clearly dominates the shift schedule, as was the case in a study of permanent night workers with six consecutive nightshifts and three off days, fairly good adjustment has been found on all days of the night week (16). Taken together, the results of these studies of different types of schedules indicate that the relative part of the nightshift period in the whole shift schedule, in addition to the number of consecutive nightshifts, is an important determinant of the type of adjustment achieved during the nightshift.

In the present study the adjustment to both night and day work was incomplete. Whether also the free days in the day week were affected was, however, not investigated. Neither was the subjects' adjustment during sleep studied, nor has it been considered in the other studies described. An investigation of these aspects of adjustment is needed before more definite conclusions about the relative merits of different types of shift schedules can be drawn. These questions will be pursued in subsequent studies.

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