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Heart rate patterns in sedentary shift work: influence of circadian rhythm, meals and personality*

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Summary. Heart rate was recorded at regular intervals during the course of 8-h sessions of simulated sedentary shift work performed for 12 consecutive days. Separate groups of subjects were assigned to one of three shifts, commencing either at 0400 hours ("morning" shift), 0800 hours ("day" shift) or 2200 hours ("night" shift). A major meal was taken during a break in the middle of each shift. In all groups heart rate fell during the pre-break period, but rose after the break in response to the meal. This pattern remained constant over the 12-day period in the morning and day shift groups, but in the night shift group a progressive rise in the general level of the readings, caused mainly by the adjustment of the circadian rhythm to the altered sleeep/wake cycle, was accompanied by systematic changes in the extent of both the pre-break fall and the post-meal rise. Comparison with the results of a control study of 24-h variation in base heart rate suggested that differential responses to the meal observed in the three shift groups may have been due, at least in part, to differences in their personality make-up. It is concluded that, although systematic patterns of heart rate can be observed in sedentary shift work, both the timing of the shift and the personality of the subject must be taken into account when assessing the changes in physiological state likely to occur during work sessions that include a major break for refreshment.

Key words: Heart rate – Shift work – Circadian rhythm – Meals – Personality

Introduction

Heart rate, like other readily measurable physiological variables such as body temperature, exhibits a circadian rhythm of significant amplitude (Smolensky et al. 1976). Although it is thus a potential index of adaptation of such rhythms to the altered sleep-wake cycles that result from shift-work, it is rarely used for this purpose because of its high degree of responsiveness to changes in the levels of various factors that are irrelevant to the main issue. These factors can be psychological (e.g. emotional arousal) or physiological (e.g. physical activity); in either case they are not easy to control in a "field" situation. Even in laboratory investigations of abnormal routines it can be difficult to maintain conditions in the state of near-constancy that would be required to allow a precise delineation of the "true" rhythm. This is well illustrated by the results obtained in a "control" study for such investigations, which aimed to determine the variation in base rate that occurs over a 24-h period of a normal sleep-wake cycle without work. The subjects were 73 young men; the study was carried out in conjunction with a parallel study of the circadian rhythm in oral temperature (Blake 1967), but was not reported at the time.

Although in this study all reasonable steps were taken to avoid psychologically arousing situations (the subjects spent most of their waking hours playing simple games, reading, or listening to the radio as they chose) and to restrict activity (subjects remained indoors throughout, no physical exertion was allowed, and readings were taken only after the subjects had remained seated for at least 5 min), it was found that heart rate was nevertheless affected by "unwanted" exogenous factors. Indeed, inspection of the mean curve (Fig. 1) shows that the effects of two such factors, in particular, largely determine the detailed shape of the curve over a substantial part of its "daytime" section. These factors are, firstly, the inevitable activity associated with getting up from bed in the morning and, secondly, the consumption of a large mid-day meal: the "recovery" from the sudden

*Dedicated to Professor J. Rutenfranz on the occasion of his 60th birthday

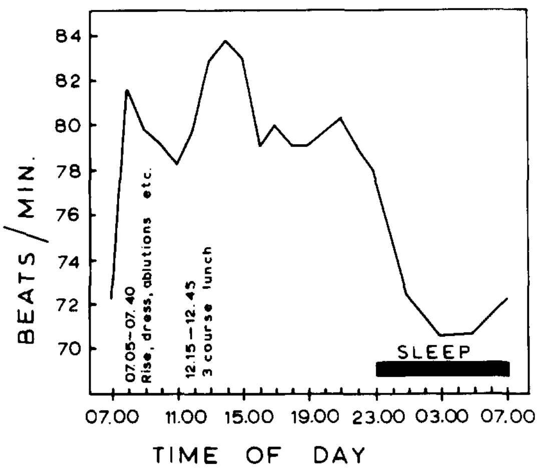

Fig. 1. "Control" study: variation in the mean base heart rate of a group of 73 young men over a 24-h period

rises in level that result from these "events" appears to be quite prolonged in both cases. Mainly because of these disturbances, it is only during sleep that the curve takes on the relatively smooth appearance characteristic of the entire 24-h curve of oral temperature observed in the same subjects (Blake 1967). Thus, unlike in the latter case, where the upper turning point of the curve was as well defined as the lower, the peak-time of the underlying rhythm in heart rate cannot readily be identified.

Despite problems of the kind demonstrated by this study, it is still possible, in the laboratory, to compare the temporal patterns of heart rate observed with differently timed work-shifts, provided that the tasks being performed and all other aspects of the on-shift routine remain the same. [See Rutenfranz et al. (1975) and Knauth (1983) for accounts of pioneering research in this area.] The data described here were obtained under conditions that met these requirements. They were collected during the course of an investigation into variations in mental efficiency over an unbroken series of 12 daily 8-h simulated work shifts commencing either at 0400 h ("morning" shift), 0800 h ("day" shift) or 2200 h ("night" shift) (Colquhoun et al. 1968). Separate groups of 10, 11 and 10 male subjects aged from 18–26 years (drawn from a common population of enlisted servicemen) were assigned to the morning, day and night shifts, respectively. The on-shift routine was identical for all three groups. It consisted of two 200-min periods of sedentary work during which tasks of signal detection and serial computation were alternated at regular intervals; these two periods were separated from each other by a 50-min meal break, and each was interrupted at the half-way point by a 10-min rest pause. Off-shift, the day-shift group slept normal hours, but sleep times were advanced by about 4 h for the morning shift group (who had to rise at 0315 h) and delayed by about 9 h for the night-shift group (who retired at 0800 h, following a post-shift breakfast).

Methods

Heart rate was measured during each shift by palpation of the radial artery for 1 min on the following occasions: commencement of shift (time 0); beginning of first rest pause (+100 min); start of meal break (+210 min); end of meal break (+260 min); beginning of second rest pause (+360 min); and termination of shift (+470 min). These measurements will be referred to as readings 1, 2, 3, 4, 5 and 6, respectively.

For the morning and day shift groups, the food given during the meal break was appropriate to the time of day, i.e. breakfast in the former case, and lunch in the latter. Both meals were substantial, as was the one taken by the night-shift group subjects, who were provided with food equivalent in content to the lunch they missed by having to sleep during the day. During the break the subjects walked about 100 m from the laboratory to a dining room to consume their meal and then returned to their seated position in the laboratory. Strict adherence to this routine ensured that the general level of activity preceding the post-break reading (reading 4) was held constant for each group. The on-shift work pattern itself guaranteed a similar constancy for readings 2, 3, 5 and 6, since in each of these cases the subjects had previously been continuously seated for 100 min while engaged in only (the same) mental work. Because it was not practicable (nor indeed desirable for motivational reasons) to exercise complete control over the subjects' behaviour outside their working hours, the level of activity preceding reading 1 could have varied somewhat in the different groups and/or from day to day; however, an attempt was made to reduce the effects of this possible variation by requiring the subjects, after their arrival at the laboratory, to sit at their work-stations for 5 min before the reading was taken.

Only decaffeinated beverages were served during the breaks in the work shifts. Since all subjects were smokers, cigarette smoking was permitted ad lib. throughout the session to avoid the problems that the imposition of restriction might create.

Results and discussion

Analysis of variance of the complete data set showed that all main effects and their interactions were statistically significant by the conservative Huynh-Feldt test: group ($P = 0.046$); day ($P < 0.0001$); time into shift ($P < 0.0001$); group × day ($P = 0.024$); group × time into shift ($P < 0.001$); day × time into shift ($P < 0.01$); and group × day × time into shift ($P < 0.01$). Although when the readings taken at the beginning of the shift (reading 1) were omitted from the analysis the level of statistical significance of both the group main effect and the group × day interaction was reduced ($P = 0.059$ and 0.053 respectively), the probabilities associated with the remaining main effects and interactions remained unchanged from

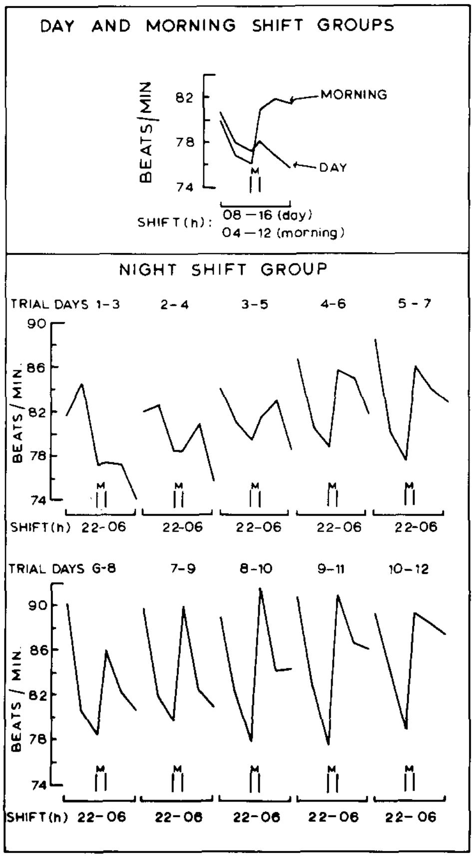

Fig. 2. Present study: on-shift changes in heart rate. *Upper panel:* overall trial means in the morning and day shift groups. *Lower panel:* 3-day running averages (weighted 1:2:1) in the night shift group. M = meal break

those given above. Thus, the results appear to have been little influenced by any systematic variations in reading 1 that may have occurred as a result of the absence of full control over pre-shift activity.

The between-group effects in this analysis were found to be mainly due to the night shift group. A separate analysis of the data from the morning and day shift groups alone showed that, although there was still a significant ($P < 0.01$) main effect of day (which was found to reflect chiefly an elevation in level of approximately 2.5 beats/min that occurred between days 5 and 7, and which remained in evidence thereafter), these two groups differed from each other only in respect of the main time into shift effect (group × time into shift interaction: $P < 0.001$). The day × time into shift interaction was not significant. The mean on-shift patterns for the two groups are shown in the upper panel of Fig. 2.

It is clear that the difference between the groups lies in the second half of the shift. In both groups the readings show a virtually identical downward trend until the meal break. After the break there is a marked elevation of the readings in the morning group, whereas at this time there is only a minimal elevation in the day group. Discussion of possible reasons for this difference will be postponed until the results for the night shift group have been described.

Separate analysis of the data from the night shift group alone revealed significant effects of both day ($P < 0.01$), time into shift ($P < 0.01$) and their interaction ($P < 0.001$). The day effect in this group, unlike in the case of the morning/day groups, was found to reflect a generally *progressive* rise in level over the 12-day period, starting from a point very close to that of the other two groups (means for days 1/2: night group 78.1 beats/min, morning/day groups 77.9 beats/min) but finishing well above (means for days 11/12: night group 85.9 beats/min, morning/day groups 80.1 beats/min). The interaction of day with time into shift also reflected a progressive change, in this case in the "shape" of the on-shift trend. To bring out the nature of this change more clearly 3-day running averages are shown in the lower panel of Fig. 2.

At the start of the trial the trend of the readings over the shift is the same as that shown by the day shift, namely a fall in rate from beginning to end. However, the actual extent of the fall is much greater; this appears to be due to the persistence of the "normal" circadian rhythm at this stage (cf. Fig. 1; the reversal of trend between readings 1 and 2 reflects a local characteristic of this rhythm in this particular group of subjects, as will be seen later). By days 3–5 the pattern has changed, and the fall in the first half of the shift is now similar to that shown by the day group (and the morning group) in both form and extent; however, after the break a post-meal elevation is to be seen (as in the morning group, though not as large). From this point on, both the pre-break fall, and the post-break elevation become steadily more pronounced until near the end of the trial. The enhancement of the pre-break fall from days 4–6 onwards may be due to the fact that the initial level from which it starts itself becomes substantially higher over this period; possible explanations for the changes observed in the post-meal section of the curve will be advanced later.

Rhythm adaptation

The extent to which the general increase in level over the course of the trial in the night group is due to adaptation of the whole circadian rhythm to the altered hours of sleep and waking can be gauged by examination of the "24-h" curves in Fig. 3. In this figure the "day 6" and "day 11" curves are comprised of the actual on-shift readings, and certain additional off-shift readings that were also taken on these days

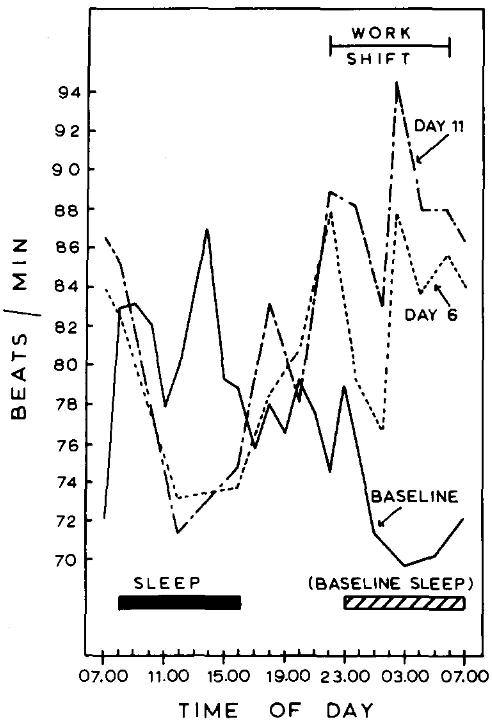

Fig. 3. Present study: "24-h" curves of heart rate in the night shift group. (For further explanation, see text)

only. The "round the clock" baseline readings were collected before the trial began, under the same conditions as described for the 24-h "control" study reported in the Introduction (note the rise between 2200 h and 2300 h in this baseline curve, referred to earlier).

Comparison of the three curves suggests that simple phase-adjustment of the rhythm could account for a large part of the increase in the level of the on-shift readings [cf. the curves obtained with a similar night shift in the study by Knauth (1983) mentioned in the Introduction]. However, although it appears from the general shape of the "day 6" and "day 11" curves that on both of these days these on-shift readings spanned the "peak" of an adjusted rhythm, the fact that this peak was higher on day 11 than on day 6 indicates that in the later stages of the trial an additional factor was affecting level. This factor could perhaps represent the cumulative effects of following an unbroken regime of daily shift-working over a protracted period; if so, it may also have been responsible for the elevation in level observed in the later stages of the trial in both the day and morning groups.

The "post-meal" effect

Whereas the progressive development of a post-meal elevation of heart rate in the night group could be ascribed to a gradual process of conditioning of the autonomic response to an intake of food at an "unusual" time, it is difficult to explain why, after completion of this process, the elevation should be so great in comparison with that seen in the day group curve after the intake of a similar amount of food at a "normal" time. The fact that the elevation in the morning group is also larger than that in the day group is similarly puzzling. It is tempting to regard the increase in the elevations as an indication of the stress induced by the abnormal sleep/waking regimes imposed on the night and morning groups. On this view, the greater increase in the night group would be a reflection of the greater displacement of sleep time involved in the night shift routine. However, this begs the question as to why such stress should reveal itself in this particular way and, in any case, it is unclear why the elevation under the normal sleep/waking routine of the day shift should be much *smaller* than that observed previously under this routine in a larger sample (cf. Fig. 1). An alternative explanation of the differences between the three groups that bears on this matter is put forward below.

The influence of personality

In an initial report on the oral temperatures taken simultaneously with the heart rate readings in the "control" study described in the Introduction, Blake (1967) used the score on one of the scales of the Heron Personality Inventory (Heron 1956) to divide the subjects into introverts and extraverts. He found a significant difference between these two groups in the overall "shape" of the 24-h curve (an earlier positioning of the "peak" and "trough" times in the introverts appeared to be primarily responsible for this difference). In a further analysis of these temperatures, Colquhoun and Folkard (1978) used a second scale provided by the Heron Inventory to identify "stables" and "neurotics" within the sample and showed that the difference between introverts and extraverts was exaggerated in the "neurotic" subjects.

Although in a contemporaneous analysis of the heart rate data from this "control" study (Blake, unpublished) no personality-related differences in the overall shape of the 24-h curve were revealed, the results of later investigations of the physiological and psychological concomitants of the "post-lunch dip" by Christie and McBrearty (1979) and Craig et al. (1981) have led the present author to re-examine the data with specific respect to the effect of personality on the increase in level observed immediately after the meal. The means of the readings at 1200 h and 1300 h (i.e. just before and just after lunch) are

Table 1. "Control" study: mean heart rate levels (beats/min) at 1200 and 1300 h in the 73 subjects grouped (a) on extraversion score and (b) on neuroticism score

Grouping		N	Heart rate level	
			1200 hours	1300 hours
(a)	Introvert	35	80.3	80.7
	Extravert	38	79.2	84.8
(b)	"Stable"	38	79.2	84.1
	"Neurotic"	35	80.3	81.5

Table 2. "Control" study: heart rate response to lunch in four groups with specific personality characteristics

Group	N	Median neuroticism score	Median introversion score	Mean change in heart rate (beats/min)
"Stable extraverts"	20	5.5	2.0	+7.0
"Stable introverts"	18	5.0	5.0	+2.6
"Neurotic extraverts"	18	9.0	2.5	+4.0
"Neurotic introverts"	17	11.0	5.0	−1.9

Table 3. Present study: post-meal-break elevation of heart rate in the three shift groups, averaged over trial days

Group	Median neuroticism score	Median introversion score	Mean elevation of heart rate (beats/min)
Day	11.0	5.0	+1.0
Night	5.5	2.5	+9.9[a]
Morning	8.5	3.5	+4.9

[a] Based on days 10–12 only

shown in Table 1 for introverts and extraverts, on the one hand, and for "stables" and "neurotics" on the other.

It can be seen that the response to the meal was greater in extraverts than in introverts and also greater in "stables" than in "neurotics". Analysis of variance showed that the first effect was statistically significant ($P = 0.014$) and the second marginally so ($P = 0.074$); there was no evidence of an interaction between them ($F < 1.0$). According to these results, which imply that the two effects are simply additive, the greatest response will be found in those subjects who are both "stable" *and* extravert and the smallest in those who are both "neurotic" *and* introvert. Table 2 confirms that this is the case (in fact, the response of the "neurotic introverts" is actually negative); it is noteworthy that this particular pattern of personality-related effects is the same as that found in the different measures considered in the studies by Christie and McBrearty (1979) and by Craig et al. (1981).

Table 3 gives the mean values of the post-meal-break elevation in heart rate in the three groups of the present study, together with the median personality scores of the groups on the two Heron scales (1956). Comparison of this table with Table 2 shows that the responses to the meal in the night and day groups are of approximately the same magnitude as those in the two personality groups most differentiated in this regard, namely the "stable extravert" and "neurotic introvert" groups, respectively (the actual *difference* between the responses in the two shift groups is, in fact, exactly the same as that between the two personality groups). Significantly, it will be seen that the Heron scores are virtually identical in the matching groups from the two studies. The magnitude of the morning group response is close to that of the "neurotic extravert" personality group; again, the Heron scores of these two groups are much the same.

These findings suggest that the differences in the post-meal elevation in the three shift groups may have been due, at least in part, to differences in the personality make-up of these groups. Insofar as this implies that the general pattern of heart rate observed in a session of sedentary work may be modified by the particular temperamental characteristics of the individual, some caution should perhaps be exercised in predicting the precise changes to be expected in any given situation from the figures presented in this report.

Conclusions

Bearing in mind the above *caveat*, it would appear that, in 8-h sessions of sedentary shift work, heart rate is likely to fall as the shift proceeds, regardless of the time at which it commences. However, if the work is interrupted for the purpose of taking a major meal, a post-break elevation will occur, and the new, higher rate may persist for some time afterwards. Although this elevation will normally appear on each of a series of shifts, it may not be seen on the first few if the meal break is taken at an "unusual" time of day.

Apart from these within-session changes in heart rate, there may also be changes in the *overall* on-shift level when an unbroken series of daily shifts is maintained for a considerable period. Typically, a slight increase is to be expected after about a week; when the timing of the shift requires a major change in sleep habits (as in night work) this increase will be superimposed on a more substantial, steady rise resulting from the adjustment of the circadian rhythm to the new sleep-waking cycle.

The detailed import of these findings for the health and efficiency of shift-workers remains to be determined, although any long-term increase in heart rate not due to circadian rhythm adjustment would seem to be undesirable *prima facie*. However, the main outcome of the investigation reported here is the demonstration that systematic patterns of heart rate *can* be observed in sedentary shift work and that the pattern will change if the timing of a shift results in an adjustment of the circadian rhythm. In addition, it is clear that since heart rate is affected by extraversion and neuroticism in the context of meals, personality differences must also be taken into account in assessing the changes in physiological state that are likely to occur over a work session that includes a major break for refreshment.

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