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Changes in the Temperature Rhythm of Submariners Following a Rapidly Rotating Watchkeeping System for a Prolonged Period

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Summary. On-watch readings of oral temperature were obtained at hourly intervals from submariners during two continuously submerged voyages of 48 days duration. The subjects followed a rapidly rotating watchkeeping system of 4-h duty-spells during the entire period. In the majority of cases, the amplitude of the circadian temperature rhythm progressively declined, and this was accompanied by a tendency for the rhythm to disintegrate into shorter periods, associated with the length of the duty spell and the particular pattern of sleep adopted. On one voyage, one subject's rhythm showed a tendency to "free-run", with a period of 24.6 h. It is concluded that the results give pointers to the kind of effect to be looked for in studies of shift-workers following similarly highly irregular patterns of work.

Key words: Circadian rhythm – Body-temperature – Submariners – Watchkeeping – Sleep

This study was concerned with a very small population of "shiftworkers", whose particular problems are probably unique. Thus, strictly speaking, the results are applicable only to this restricted population; nevertheless, to the extent that the shift system followed by these people represents probably the "extreme" case (a) of irregularity of work hours, (b) of rapidity of shift-cycle rotation and (c) of duration of unbroken shift working, the findings may give "pointers" to the kind of changes to be looked for in the temperature rhythm of groups of people who follow highly irregular work-patterns, e. g., train crews.

Oral temperatures when on watch were recorded at hourly intervals from sonar operators on a submarine during two continuously submerged voyages, each of 48 days duration. The "rotating" watchkeeping system followed by the subjects is shown in Table 1. The temperature readings from each watch were collated to give a "24-h" set for each 3-day cycle. This collation assumes, of course, stationarity of the rhythm

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Table 1. The rotating watchkeeping system

	Day 1	Day 2	Day 3
Times	00.00–04.00	04.00–08.00	12.00–16.00
Of	08.00–12.00	16.00–20.00	
Watches	20.00–00.00		

over a 3-day period; however, since it transpired that those changes that were observed in the rhythm were relatively slow (see below), this assumption seems, post hoc, to have been warranted.

Readings from the second voyage were somewhat fragmented, owing to an outbreak of a presumed viral infection among the crew. Thus, in what follows we will be concerned primarily with the data obtained on the first voyage from 8 subjects for whom reliable records were obtained for the whole 48-day period.

Results

1. Whole Data Series

Prior to "collating" over 3-day cycles as described above, the entire data series of each subject were analysed in the actual order in which they were obtained, by a programme which allowed unequally spaced points to be fitted by a sine-curve. Curves were fitted with periods ranging from 2.2 h to 40.0 h (to assess the fit of the circadian period and its harmonics, and the harmonics of the 72 h watchkeeping cycle) and 70.0 h to 75.0 h (for an effect from the fundamental period of the watchkeeping cycle). Within these ranges increments in the period were 0.1 h.

The data of all subjects were fitted very highly significantly ($p < 0.001$) by the curve with a 24.0 h period; however, the data of only one of the subjects showed the highest F-ratio (goodness of fit of the curve assessed by an analysis of variance method) at this period. Of the remaining 7 subjects, the best fitting period for six was 24.1 h, and for one 24.6 h; this suggests that there was some "phase drifting" in each of these 7 subjects, which was sufficiently marked in one case to warrant the interpretation that his rhythm was "free running". Amplitudes of the 24.0 h curve ranged from 0.19–0.51°F; times of acrophase were all between 17.8 and 19.5 h, i. e., a little later than the acrophase time (17.5 h) of a sine-wave fitted to the "normal" rhythm (as given in Colquhoun et al., 1968) for subjects from the same general population.

Many other periods which are (approximately) harmonics of a 72 h period fitted the data series significantly (see Table 2). It is considered that some of these periods resulted from an interaction of the data-sampling pattern with the circadian rhythm. However, this does not apply to periods of 8 h or 4 h[1], and it is noteworthy that five of the subjects showed a significant period in the range 7.7–8.3 h, and three, one of 4.0 h. The latter could well have resulted from a systematic within-watch effect. The period around 8 h could have resulted from an interaction between the watchkeeping rota, sleeping habits, and the circadian rhythm. The most probable way in which this

[1] This conclusion is based on an analysis of the "normal" rhythm (as given in Colquhoun et al., 1968), in which the readings from the points corresponding in time to the present sampling pattern were run through the same programme (see Colquhoun, Paine and Fort, 1975)

Table 2. Approximate harmonics of the 72.0 h "rotating" watch-keeping schedule, with the frequency with which they emerged as significant from the analysis of the temperature readings. The range

Period	No. Subjects	Period Range
72.1 h [a]	8	70.4–72.9 h
36.0 h [a]	8	35.9–36.0 h
24.0 h [a]	8	24.0–24.1 h
18.0 h [a]	7	17.8–18.0 h
14.4 h [a]	8	14.2–14.7 h
12.0 h [a]	8	12.0–12.2 h
10.3 h [a]	6	10.1–10.3 h
9.0 h [a]	8	9.0– 9.1 h
8.0 h	5	7.7– 8.3 h
7.2 h [a]	8	6.9–7.4 h
6.5 h	2	6.3–6.4 h
6.0 h		
5.5 h	4	5.5 h
5.1 h	2	5.2 h
4.8 h		
4.5 h		
4.2 h		
4.0 h	3	4.0 h

significant from the analysis of the temperature readings. The range
considered to represent an harmonic is also given

could give rise to an 8 h period would be for temperature to be lowered at 16.00 and raised at 04.00. Analyses of sleep logs kept by the subjects showed that they often slept before the 16.00–20.00 watch (making up sleep lost on night watches), and tended to stay awake before the 04.00–08.00 watch (Colquhoun et al., 1978). These habits would have the appropriate effects on temperature.

2. One-Cycle Sections

In order to gain estimates of any trends in changes in the temperature rhythm during the voyage, curves based on a 24.0 h period were fitted to the "collated" readings obtained from each subject in each of the 16, 3-day cycles of the watchkeeping system completed during the voyage. Both the fundamental (24 h) curve and a "combined" (24 h + first harmonic) curve were fitted, since the latter has been shown to provide a significantly better fit to the "normal" rhythm (Colquhoun et al., 1978). In the present case 87 of the 128 sets of data were fitted significantly by the fundamental curve, and 113 by the "combined" curve. However, since the overall trends observed were similar in both cases, only the results from the fundamental curve will be considered here.

The amplitude of only one of the 8 subjects was maintained near its initial value throughout the voyage (this was the same subject for whom analysis of the data for the whole series showed the "best fit" at 24.0 h). The amplitude of the remaining 7 subjects tended to decline. Analysis of variance of the data from all 8 subjects showed that the overall differences in amplitude between the 16 cycles were statistically very highly significant ($F = 3.21, P < 0.001$). The downward trend of the mean amplitude

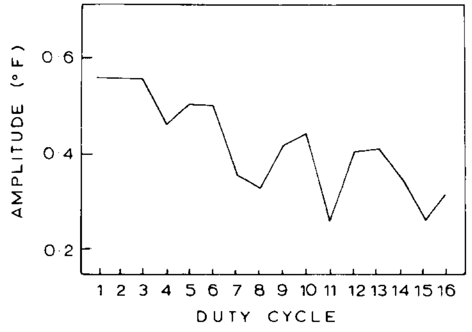

Fig. 1. Mean amplitude of the fundamental curve in successive duty cycles

over successive cycles is shown in Fig. 1. This trend was found to be statistically significant by the Mean Square Successive Difference Ratio (MSSDR) test (Hart, 1942a, 1942b; von Neuman, 1941) ($\eta = 0.80, 0.001 < P < 0.01$).

The above analyses make no allowance for the significance or otherwise of the fit of the curve to any particular set of data. A MSSDR test applied to the means of the logs of the F-ratios obtained from separate analyses of variance of the data from successive cycles showed a statistically significant downward trend ($\eta = 0.84, 0.001 < P < 0.01$). This indicates that the simple sine wave model became decreasingly appropriate as the voyage continued. The decline in mean amplitude is thus probably secondary to the decline in the goodness of fit of the sine curve.

Examination of the phasing of the rhythms showed that the variation in times of acrophase in successive cycles differed considerably in individuals. One subject (the individual whose rhythm maintained its amplitude) exhibited an acrophase which was always between 16 h and 20 h. The acrophase times of 6 of the remaining subjects became progressively more variable, and in that subject for whom the "whole series" analysis of the data showed a "best fit" for a period of 24.6 h, the acrophase, as might be expected, drifted progressively later in time in successive cycles (see Fig. 2).

The significant 4 h and 8 h periods that appeared in the "whole series" analysis of the data tended to show up in the later stages of the voyage in the present analysis. In one subject an 8 h period provided the best fit for 6 of the 16 cycles; in another, a 4 h period provided the best fit for cycle 14, and an 8 h period for cycles 15 and 16. This suggests that for the latter subject (and probably also the former) the circadian rhythm was disintegrating as the voyage progressed.

3. Second Voyage

The twelve subjects observed on the second voyage included seven who had also been on the first voyage. However, from the temperature readings collected on the two occasions it was only possible to identify one of these seven individuals as the same person. This was the subject who, on the first voyage, showed a strong and consistent "normal" rhythm with a 24.0 h period; in the second voyage his rhythm exhibited the same characteristics. The subject whose rhythm appeared to "free run" in the first voyage did not show this behaviour in the second.

Despite these intra-individual discrepancies, and notwithstanding the somewhat fragmented nature of the data on the second voyage, the overall results from the

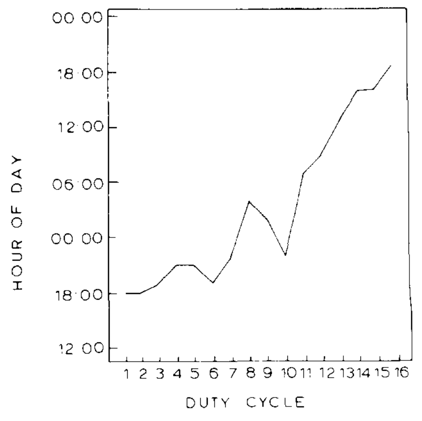

Fig. 2. Time of acrophase of the fundamental curve for one subject in successive duty cycles

latter were similar to those from the first voyage. Thus the mean amplitude again declined over successive cycles, and the "goodness of fit" of the sine-wave model varied significantly between cycles (though not in as systematic a manner as on the first voyage). The phasing of the rhythm again became more variable as the voyage progressed; the range in times of acrophase was from 9 to 13 hours during the first 5 cycles, whereas later in the patrol it was from 11 to 19 hours. Analyses of the whole data series revealed a significant period of 8 h in 6 of the 12 subjects, and one of 4 h in 7 of them.

Conclusions

It would seem clear that the particular and rapid rotation cycle of 4-h shifts followed by the subjects in this study resulted in progressive changes in the circadian rhythm of body temperature in the majority of them. The most general finding was a decline in the amplitude of the rhythm, but, in individual cases, this was accompanied either by a tendency for the period of the rhythm to lengthen, or for the rhythm to disintegrate into periods of less than 24 h. The consequences of these changes for either health or efficiency are not as yet known. Nor is it known whether such changes in the rhythm occur in other groups subjected to similarly highly irregular hours of work over much longer, though intermittently interrupted, periods. Nevertheless, it would appear worthwhile, in studies of people following such schedules, to look in particular for signs of these changes, and, if they are found to occur, to establish whether they are associated with other physiological, psychological, or psychosocial disturbances that may be ovserved.

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