

# Sleep and Circadian Phase in a Ship's Crew

Josephine Arendt,<sup>\*,1</sup> Benita Middleton,<sup>\*</sup> Peter Williams,<sup>†</sup> Gavin Francis,<sup>‡</sup> and Claire Luke<sup>\*</sup>

<sup>\*</sup>*School of Biomedical and Molecular Sciences, University of Surrey, Guildford, United Kingdom,*

<sup>†</sup>*Department of Mathematics and Statistics, University of Surrey, Guildford, United Kingdom, and*

<sup>‡</sup>*British Antarctic Survey Medical Unit, Derriford Hospital, Plymouth, United Kingdom*

**Abstract** Numerous factors influence the increased health risks of seamen. This study investigated sleep (by actigraphy) and the adaptation of the internal clock in watch-keeping crew compared to day workers, as possible contributory factors. Fourteen watch keepers, 4 h on, 8 h off (0800-1200/2000-2400 h, 1200-1600/2400-0400 h, 1600-2000/0400-0800 h) (fixed schedule,  $n = 6$ ; rotating by delay weekly,  $n = 8$ ), and 12 day workers participated during a voyage from the United Kingdom to Antarctica. They kept daily sleep diaries and wore wrist monitors for continuous recording of activity. Sleep parameters were derived from activity using the manufacturer's software and analyzed by repeated-measures ANOVA using SAS 8.2. Sequential urine samples were collected for 48 h weekly for 6-sulphatoxymelatonin measurement as an index of circadian rhythm timing. Individuals working watches of 1200-1600/2400-0400 h and 1600-2000/0400-0800 h had 2 sleeps daily, analyzed separately as main sleep (longest) and 2nd sleep. Main sleep duration was shorter in watch keepers than in day workers ( $p < 0.0001$ ). Objective sleep quality was significantly compromised in rotaters compared to both day workers and fixed watch keepers, the most striking comparisons being sleep efficiency (percentage desired sleep time spent sleeping) main sleep ( $p < 0.0001$ ) and sleep fragmentation (an index of restlessness) main sleep ( $p < 0.0001$ ). The 2nd sleep was substantially less efficient than was the main sleep ( $p < 0.0001$ ) for all watch keepers. There were few significant differences in sleep between the different watches in rotating watch keepers. Circadian timing remained constant in day workers. Timing of the 6-sulphatoxymelatonin rhythm was later for the watch of 1200-1600/2400-0400 h than for all others (1200-1600/2400-0400 h,  $5.90 \pm 0.85$  h; 1600-2000/0400-0800 h,  $1.5 \pm 0.64$  h; 0800-1200/2000-2400 h,  $2.72 \pm 0.76$  h; days,  $2.09 \pm 0.68$  h [decimal hours, mean  $\pm$  SEM]: ANOVA,  $p < 0.01$ ). This study identifies weekly changes in watch time as a cause of poor sleep in watch keepers. The most likely mechanism is the inability of the internal clock to adapt rapidly to abrupt changes in schedule.

**Key words** sleep, shift work, melatonin, light, rhythm, watch keeping, crew

Night-shift work is a recognized problem of the 24/7 society. Marine watch keeping is a specialized example of out-of-hours work with the added complication

that long voyages frequently involve rough weather, time zone change, and sometimes rapid changes in day length. Shift workers have more health problems

1. To whom all correspondence should be addressed: Josephine Arendt, Centre for Chronobiology, School of Biomedical and Molecular Sciences, University of Surrey, Guildford, Surrey, GU2 7XH UK; e-mail: [arendtjo@aol.com](mailto:arendtjo@aol.com) (preferred) or [j.arendt@surrey.ac.uk](mailto:j.arendt@surrey.ac.uk).

JOURNAL OF BIOLOGICAL RHYTHMS, Vol. 21 No. 3, June 2006 214-221

DOI: 10.1177/0748730405285278

© 2006 Sage Publications

than does the general population, for example, an increased risk of cardiovascular disease (Knutsson and Boggild, 2000) and breast cancer in women (Schernhammer et al., 2001), and night shift work is associated with increased work-related accident rate (Smith et al., 1994). Seafarers are reported to have many more work-related accidents than does the onshore population (Roberts and Hansen, 2002).

Fatigue is a recognized problem in marine operations. Smith et al. (2001) cited a 1995 National Union of Marine, Aviation and Shipping Transport Officers report that concluded that reduced crew size was the main cause of fatigue in seafarers. However, scheduled work hours may lead to imposed work during the inherent (circadian) daily peak in fatigue and the lowest point of alertness and performance (Akerstedt et al., 1982; Lowden et al., 2004). Folkard (1997) reported that collisions at sea were most likely to occur at about this time in a normal daily cycle (0600-0700 h), although accidents on offshore oil industry support vessels appear to peak around 1300 to 1400 h (Smith et al., 2001).

Very few studies of fatigue and sleep in seafarers exist (for reviews, see Colquhoun, 1985; Condon et al., 1986; Smith et al., 2001), and the majority concern naval personnel. Subjective, rather than objective, measures of sleep have been employed to date. Even fewer studies have evaluated the state of the circadian clock in marine watch keepers. Only 1 study in the literature has used melatonin (in saliva) as a marker rhythm in marine operations, and this was in submarines (Kelly et al., 1999), where subjects free ran.

We have combined the use of the melatonin metabolite 6-sulphatoxymelatonin (aMT6s) in urine, as a marker rhythm, and actigraphic evaluation of sleep to provide 2 objective measures of adaptation to watch keeping. We have simultaneously evaluated fixed watch keepers, rotating watch keepers, and day workers during a voyage from the United Kingdom to Antarctica.

## MATERIALS AND METHODS

### Subjects and Conditions

Ethical permission for this study was obtained from the University of Surrey Advisory Committee on Ethics. The participants were recruited from 2 crews working consecutively on the same ship: the RRS *Ernest Shackleton*, conveying personnel and cargo to British Antarctic Survey Bases. The ship left

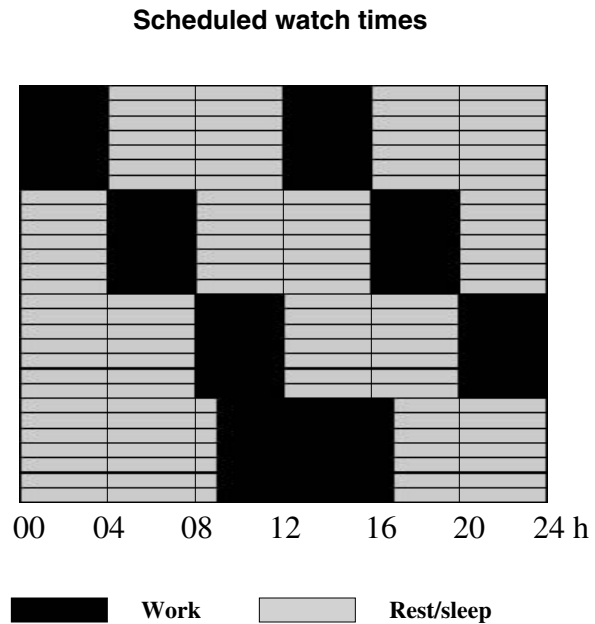


Figure 1. Diagram of scheduled watch times in rotating watch keepers.

Immingham on 31 October 2002, traveled to the Falkland Islands via Montevideo, then to South Georgia, via the Weddell Sea to Halley Bay, Coats Land, Antarctica, 75 °S, and then back to the Falkland Islands. The crew changed at Montevideo. Three time zones were crossed between the United Kingdom and the Falkland Islands, the ship subsequently remaining on GMT -3. Records of wind speed and sea state, sunrise and sunset, and daily position of the ship were taken from the ship's log. The period of daylight ranged from 9.28 to 13.46 h (1st crew) and 16.27 to 24 h with 8 days of 24-h light during recording from the 2nd crew.

The watches worked were 4 h on and 8 h off, with officers working fixed watches and the seamen working rotating watches that changed weekly. Day workers generally worked 9 to 17 h, except for 2 cooks who worked approximately 6 to 19 h with breaks during the day. Watch times were 1600-2000/0400-0800 h (fixed watch, 1st officers), 1200-1600/2400-0400 h (fixed watch, 2nd officers), and 0800-1200/2000-2400 h (fixed watch, 3rd officers). The seamen worked the same watch times in the sequence 1200-1600/2400-0400 h, 1600-2000/0400-0800 h, 0800-1200/2000-2400 h and then day work, each schedule being worked for a week at a time with a changeover day on a Sunday (Fig. 1).

Twenty-six participants, 25 men and 1 woman, aged  $37.8 \pm 10.8$  years (mean  $\pm$  SD), volunteered to

take part. Four rotating watch keepers (men), 3 fixed watch keepers (1 woman, 2 men), and 4 day workers (men) were recruited from the 1st crew. Four rotating watch keepers (men), 3 fixed watch keepers (men), and 8 day workers (men) were recruited from the 2nd crew (including 4 supernumeraries who worked part-time during the day). All but 6 of the subjects (one 3rd officer and 1 seaman of the 1st crew and 4 supernumeraries of the 2nd crew) had previously worked as crew on this route. All gave informed consent, and the ship's doctor attested to their fitness to take part.

### Activity/Sleep and Light Recording

Each participant wore a wrist-mounted activity and light monitor, ActiwatchL (AWL), kindly provided by Cambridge Neurotechnology Ltd. (Cambridge, UK), on the nondominant wrist for the duration of the voyage, except when showering. The monitors were set to record for 30-sec epochs and were downloaded approximately every 10 to 11 days. Motion and light were also recorded continuously on the bridge at the point of maximum movement and light exposure. The participants kept daily sleep diaries (bedtime, trying to start sleep time, number and duration of wake-up periods, wake time, and get-up time).

Sequential urine samples during specified 4-h intervals (0800-1200 h, 1200-1600 h, etc., longer over sleep) were collected for 48 h at the end of each week from Thursday to Saturday (36 h on 1 occasion, 1st crew, to avoid the "crossing the equator" ceremony) for circadian phase assessment, using urinary production of aMT6s. The volume of each sample was recorded and an aliquot frozen for transport to the University of Surrey.

## ANALYSIS

### Sleep Parameters

Activity records were edited to exclude incomplete days and cargo loading or discharge days (due to schedule changes). The 4 sleep outcomes modeled were actual sleep time (duration in hours); efficiency, using the equation  $(100 * [\text{actual sleep time} / (\text{wake-up time} - \text{trying to start sleep time})])$ ; fragmentation index (the addition of percentage time spent moving and the percentage immobility phases of 1 min: an indicator of restlessness); and sleep latency (time to get to sleep). These were derived from activity records using sleep diaries and the manufacturer's software. Two sleeps

per day were present in the vast majority of the records for 1200-1600/2400-0400 h and 1600-2000/0400-0800 h. These were classified by length as main and 2nd sleep for each day and analyzed separately. Four day workers reported very occasional 2nd sleeps (naps) that were not included in the statistical analysis. Naps were not reported by the other subjects.

Descriptive statistics were derived for each of the 4 sleep outcomes in relation to main sleep, 2nd sleep, and over both sleeps (the latter involving the sum of main sleep and 2nd sleep [if there was a 2nd sleep] for sleep duration and the average of main sleep and 2nd sleep for the other 3 sleep outcomes).

Each of these 12 outcomes was modeled against the following: crew (November, 1st crew; December-January, 2nd crew), type of shift (day, fixed, rotating), week of voyage (1st, later), hours of light per day, and hours of light between 2400 and 0400 h. Given the nature of these independent variables (some categorical and some continuous) and the repeated-measures scenario, the general mixed model (Ware, 1985) using the method of maximum likelihood to estimate parameters was fitted using the PROC MIXED procedure in SAS version 8.2.

The modeling exercise was repeated for rotating watch keepers only, with watch time (1200-1600/2400-0400 h, 1600-2000/0400-0800 h, 0800-1200/2000-2400 h, days, watch changeover day) replacing type of shift. A variable representing the start (days 1-2) or the end (days 3-7) of a 7-day watch was also included in the model.

### aMT6s

The concentration of aMT6s in urine samples was determined by radioimmunoassay (Aldhous and Arendt, 1988). The mean assay coefficient of variation over the range 3.9 to 42.7 ng/mL was 12.5%. The peak time (acrophase) of the aMT6s rhythm was derived by cosinor analysis for urinary data (program provided by Dr. D. S. Minors, University of Manchester, UK). Data were considered acceptable if the cosinor fit was significant at the 95% level or if the fit was significant at >80% level and the percentage of variance (percentage rhythm) accounted for by the cosine curve was greater than 50%.

Descriptive statistics were derived using acrophases from cosinor analysis. For the fixed watch keepers, individual data were averaged over all available collections. Single-factor ANOVA (factor week of voyage) was applied to the data from day workers. Single-factor ANOVA (factor watch type) was applied

to the data from rotating watch keepers. Two-factor ANOVA (factors watch type and time of day) was then applied to the raw data. Post hoc Student *t* tests were used to identify differences between watch types.

Unless stated otherwise, data are given as mean  $\pm$  SD. Time is reported in decimal hours.

## RESULTS

### General

Seven weeks of activity recording were available for analysis, 3 weeks for the 1st crew and 4 for the 2nd crew. Rough sea ("heavy swell/pitching and rolling/rough") was experienced during the 1st week of recording for each crew (3 days, 1st crew; 2 days, 2nd crew) and for approximately 36 h during the last week of recording for the 2nd crew. Otherwise, the weather and sea state were moderate to calm for the rest of the voyage. The ship's movement was hardly registered by the fixed AWLs on the bridge. Light recording was compromised in individuals working in protective clothing out of doors when the sensor may have been obscured. In consequence of this, the daylight records from the ship's log were used as an indication of light exposure.

Compliance with activity monitoring was good with 93% (range, 81%-100%) day workers, 89% (range, 71%-97%) rotators, and 92% (range, 82%-100%) fixed watch keepers, of the maximum possible data available for analysis.

Compliance with urine collection was also good; however, 2 fixed watch keepers missed 1 of 3 collections (2nd and 3rd week of voyage, respectively, 1st crew), and sample volumes were missing in 2 of 4 collections from another fixed watch keeper (2nd and 4th week of voyage, 2nd crew) and in 1 collection from a rotating watch keeper (2nd week of voyage). Two rotating watch keepers (1st crew) completed 24 h of the 48-h collection during the 3rd week of the voyage. All available urine data were included in the analysis.

Examples of personal activity records for different types of watches are shown in Figure 2.

### Sleep Outcomes

The most important results comparing day workers, fixed watch keepers, and rotating watch keepers are summarized in Table 1. The main sleep duration was shorter in watch keepers than in day workers; however, when total sleep duration was considered (main sleep plus 2nd sleep), rotating watch keepers

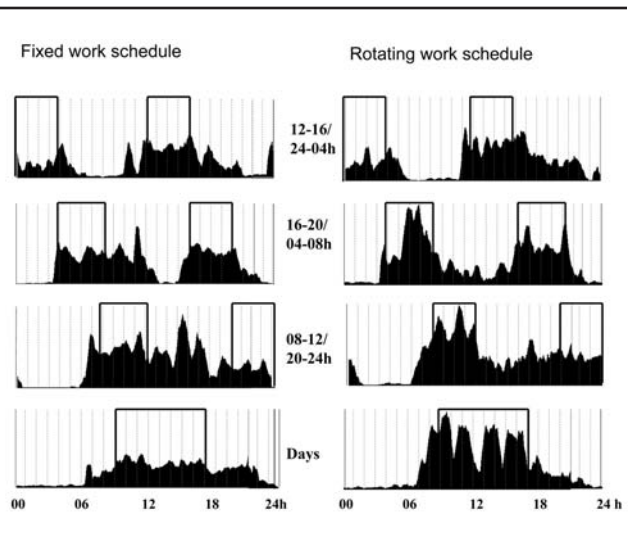


Figure 2. Examples of recorded activity from individual watch keepers during different fixed and rotating watch schedules. Four to 6 days of data were averaged over 10-min epochs in each case, avoiding time zone changes, Saturdays (watch changeover days), and Sundays. The same rotating watch keeper (1st crew) provided the data shown in the top 3 panels on the right side of the figure. Scheduled work times are shown by the thick vertical lines. Note 2 periods of sleep in both fixed and rotating watch keepers during the watches of 1200-1600/2400-0400 h and 1600-2000/0400-0800 h, with little daytime sleep in the rotating watch keeper working 1600-2000/0400-0800 h. The main sleep was taken after the watch of 1200-1600/2400-0400 h but before the subsequent watch of 1600-2000/0400-0800 h.

slept longer than did fixed watch keepers and day workers. Sleep efficiency was significantly compromised in rotators compared to both day workers and fixed watch keepers. Sleep fragmentation was high in rotators. In contrast, fixed watch keepers had less restless sleep than did both rotating watch keepers and day workers. Sleep latency was longer in rotators than in fixed watch keepers for the 2nd sleep and all sleeps combined. In addition to the tabulated data, the 2nd sleep was substantially less efficient than was the main sleep ( $p < 0.0001$ ) for all watch keepers. Main sleep duration (but not total sleep duration) was slightly longer in the 1st crew compared to the 2nd crew ( $5.36 \pm 0.97$  h vs.  $5.31 \pm 0.81$  h,  $p < 0.05$ ). The 1st week of the voyage for both crews had shorter duration ( $4.91 \pm 0.80$  h vs.  $5.47 \pm 0.96$  h,  $p < 0.01$ ) and latency ( $0.18 \pm 0.11$  h vs.  $0.23 \pm 0.19$  h,  $p < 0.05$ ) of the main sleep than did subsequent weeks. The presence of 1 h or more of daylight between 2400 and 0400 h was associated overall with a longer main sleep (an increase of  $7.4 \pm 7.1$  min,  $p < 0.05$ ).

There were few significant differences in sleep between the different watches in rotating watch keepers. However, main sleep duration was shorter for the



Table 1. Summary Statistics in Major Sleep Outcomes Based on Subject Means

Outcome/Sleep	All Subjects			Fixed Watch Keepers			Rotating Watch Keepers			Day Workers		
	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
Sleep duration (decimal h)												
Main	5.33	0.86	26	4.66	0.51	6 <sup>a</sup>	4.83	0.58	8 <sup>a</sup>	6.00	0.67	12 <sup>b</sup>
2nd*	2.67	0.70	12	2.11	0.37	4 <sup>e</sup>	2.95	0.66	8 <sup>f</sup>	N/A**		
Total*	6.17	0.77	26	5.83	0.64	6 <sup>a</sup>	6.70	0.79	8 <sup>b</sup>	6.00	0.67	12 <sup>a</sup>
Sleep efficiency (%)												
Main	80.10	4.75	26	83.01	4.26	6 <sup>a</sup>	77.28	3.15	8 <sup>b</sup>	80.52	5.10	12 <sup>c</sup>
2nd	73.93	5.95	12	79.67	4.16	4 <sup>a</sup>	71.06	4.46	8 <sup>b</sup>	N/A**		
All	78.15	5.85	38	81.67	4.34	10 <sup>a</sup>	74.17	4.92	16 <sup>b</sup>	80.52	5.10	12 <sup>c</sup>
Fragmentation index												
Main	38.41	10.67	26	31.70	9.60	6 <sup>a</sup>	42.36	7.84	8 <sup>b</sup>	39.14	11.88	12 <sup>c</sup>
2nd	43.36	10.49	12	34.53	8.36	4 <sup>d</sup>	47.78	8.73	8 <sup>c</sup>	N/A**		
All	39.98	10.72	38	32.84	8.75	10 <sup>a</sup>	45.07	8.49	16 <sup>b</sup>	39.14	11.88	12 <sup>a</sup>
Sleep latency (decimal h)												
Main	0.21	0.14	26	0.15	0.10	6	0.25	0.09	8	0.22	0.19	12
2nd	0.19	0.09	12	0.12	0.04	4 <sup>g</sup>	0.22	0.09	8 <sup>h</sup>	N/A**		
All	0.20	0.13	38	0.14	0.08	10 <sup>d</sup>	0.23	0.09	16 <sup>e</sup>	0.22	0.19	12 <sup>c</sup>

NOTE: For each row, values with different letters a, b, c differ significantly at  $p < 0.0001$ ; d, e, f differ significantly at  $p < 0.01$ ; g, h differ significantly at  $p < 0.05$ . \*Absent 2nd sleep times were not used in calculating 2nd sleep time means and SDs. However, for the calculation of total sleep duration, these 2nd sleep times were set to 0. Thus, the means for total sleep durations appear comparatively low. \*\*Four-day workers had very occasional 2nd sleeps (naps) that were not included in the statistical analysis (N/A = not applicable).

"night" watches of 1600-2000/0400-0800 h ( $4.39 \pm 0.54$  h,  $n = 7$ ) and 1200-1600/2400-0400 h ( $4.02 \pm 0.81$  h,  $n = 7$ ), together with the "changeover day" ( $4.87 \pm 0.93$  h,  $n = 8$ ), than for the "day" watches ( $5.81 \pm 1.07$  h,  $n = 7$ ;  $p < 0.0001$ ). For the 2nd sleep only, the changeover day had a greater fragmentation index ( $54.39 \pm 9.12$ ,  $n = 8$ ) than did the "night watches" ( $50.98 \pm 19.70$ ,  $n = 7$ ;  $49.54 \pm 14.57$ ,  $n = 7$ ) and day watch ( $41.88 \pm 9.74$ ,  $n = 6$ ), the 0800-1200/2000-2400 h watch having the least fragmentation ( $39.94 \pm 17.69$ ,  $n = 6$ ;  $p < 0.05$ ). Sleeps were uniformly poor; none achieved 80% efficiency.

In a separate analysis of the 1st crew (November) only, no statistically significant relationships were found between the sleep outcomes and the time zone changes.

### aMT6s Profiles

There were no differences in the timing of the aMT6s rhythm in day workers between crews or during the voyage. There were no significant differences in amplitude between watch types. However, there were significant changes in circadian phase between watches (Fig. 3). The acrophase of 1200-1600/2400-0400 h was later than all others in rotating watch keepers (1200-1600/2400-0400 h,  $5.90 \pm 0.85$  h,  $n = 8$ ; 1600-2000/0400-0800 h,  $1.50 \pm 0.64$  h,  $n = 7$ ;

0800-1200/2000-2400 h,  $2.72 \pm 0.76$  h,  $n = 6$ ; days,  $2.09 \pm 0.68$  h,  $n = 8$ ;  $p < 0.01$ ; decimal hours, mean  $\pm$  SEM). Corresponding main sleep mean bedtimes were  $4.44 \pm 0.15$  h,  $9.80 \pm 0.31$  h,  $1.15 \pm 0.50$  h, and  $22.02 \pm 0.31$  h, respectively (mean  $\pm$  SEM). The late acrophase in the watch from 2400 to 0400 h was also seen in the averaged individual data in fixed watch keepers (1200-1600/2400-0400 h, 3.98 h; 1600-2000/0400-0800 h, 1.00 h; 0800-1200/2000-2400 h, 1.63 h;  $n = 2$  in each case). The largest change in timing of the internal clock as evidenced by calculated aMT6s timing was between the watches from 1200-1600/2400-0400 h and 1600-2000/0400-0800 h.

### DISCUSSION AND CONCLUSIONS

In comparison with published data for normal, healthy sleepers onshore, none of the crew had high sleep efficiency: 90% efficiency may be reported in some healthy volunteers, evaluated by actigraphy (e.g., Leger et al., 2002) with good correspondence between actigraphy and polysomnography (Cole et al., 1992; Ancoli-Israel et al., 2003). No individual in this study achieved 90% overall efficiency. However, the efficiencies for the fixed watch keepers and day workers

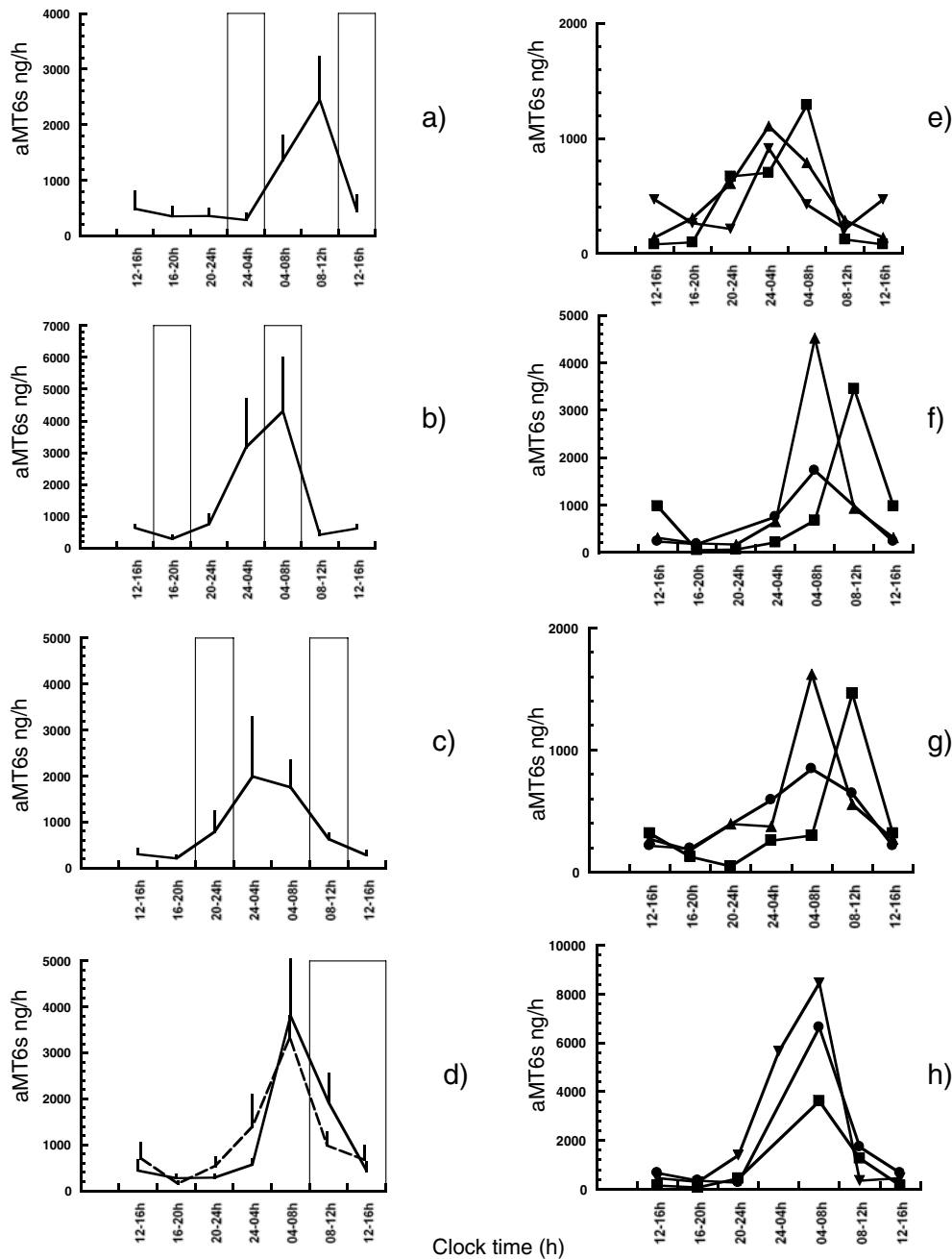


Figure 3. Left panel: group mean values for urinary 6-sulphatoxymelatonin (aMT6s; ng/h + SEM) from rotating watch keepers: (a) 1200-1600/2400-0400 h, (b) 1600-2000/0400-0800 h, (c) 0800-1200/2000-2400 h, and (d) days. The broken line is the profile from fixed-day workers for comparison. The 48-h data (on 1 occasion, 36 h) were averaged over 24 h, and the 1200 to 1600 h data point is repeated for clarity. The average  $n$  for each data point ranges from 4 to 8. Note changes of scale. Hours of work are indicated by the vertical lines. Right panel: (e-h) aMT6s profiles from individual rotating watch keepers: (e, f) 1st crew; (g, h) 2nd crew. Watches were as follows: ■, 1200-1600/2400-0400 h; ▼, 1600-2000/0400-0800 h; ▲, 0800-1200/2000-2400 h; ●, days. Subjects (e) to (g) show adaptation to the watch of 1200-1600/2400-0400 h; subject (h) does not adapt. He was the oldest participant and had the highest production of aMT6s. Note changes of scale.

were comparable to other data collected by the authors using the Actiwatch hardware and software in other working populations and experimental volunteers. For example, 16 oil installation workers aged  $42.9 \pm$

10.5 years working 6- to 18-h days offshore recorded  $83.6\% \pm 8.5\%$  sleep efficiency (Gibbs et al., 2004).

Irrespective of watch, the rotating watch keepers had worse sleep in terms of efficiency and fragmentation

than did fixed watch keepers or day workers. This is probably because of the weekly circadian disruption due to change of watch type. Previous data from oil installation workers who were working a week of nights followed by a week of days or vice versa have clearly shown decrements in sleep parameters associated with the shift change (Parkes et al., 1997; Barnes et al., 1998). It is unlikely that daytime noise contributed to poor sleep because quiet was enforced outside crew cabins during the daytime.

Shortened sleep duration has previously been noted in fixed watch keepers (Rutenfranz et al., 1988; Howarth et al., 1999), although a similar duration was found in day workers here and in day workers on off-shore oil installations ( $6.26 \pm 1.16$  h,  $N = 16$ ; Gibbs et al., 2004). It is possible that some day workers and 0800-1200/2000-2400 h watch keepers took unrecorded naps, which would effectively have increased total sleep duration. Identification of short naps from actigraphy records only is difficult, in view of the tendency of the equipment to record sleep when subjects are immobile but awake. Thus, a conservative approach was to use only recorded sleeps.

Fixed watches appeared to favor adaptation with respect to quality of sleep (objective sleep efficiency, fragmentation, and latency). In general, their objective sleep quality was better than that of both day workers and rotating watch keepers. The increase in total sleep duration (i.e., main sleep plus 2nd sleep) in rotating watch keepers may possibly compensate in part for the poor efficiency.

The Actiwatch algorithm can overestimate sleep time when subjects are recumbent, unmoving but awake (Lockley et al., 1999; Ancoli-Israel et al., 2003). Some of the participants went to bed to watch videos during their leisure periods. To at least partially counter overestimation of sleep time, with the consequent underestimation in sleep efficiency, the latter was calculated as  $100 \times [\text{actual sleep time} / (\text{wake-up time} - \text{trying to start sleep time})]$ . The more usual calculation is  $100 \times [\text{actual sleep time} / \text{time in bed}]$ . Nevertheless, overestimation of actual sleep time is still a possibility.

Only the 1200-1600/2400-0400 h watch was associated with detectable circadian adaptation (by delay). Nevertheless, the calculated peak time for aMT6s in this shift ( $5.90 \pm 0.85$  h [mean  $\pm$  SEM]) was not as late as would be expected if full adaptation had occurred. The average bedtime for the main sleep was 4.44 h, and thus the peak time was found at the beginning of the sleep period (for both rotating and fixed watch keepers) rather than in the middle of the sleep period, as in normally adapted individuals (Bojkowski et al.,

1987). The main sleep was taken after the watch during the 1200-1600/2400-0400 h week, possibly reinforcing the circadian delay. However, the individual data were variable as evidenced by the large standard errors.

The 1600-2000/0400-0800 h watch had the earliest peak time in both rotators and fixed watch keepers, and a substantial amount of sleep was obtained prior to the 0400-h start time. The change from 1200-1600/2400-0400 h to 1600-2000/0400-0800 h therefore involved the greatest phase change and desynchrony. It has been recommended by some that delaying shift patterns is the most likely to induce adaptation, but in this case, the choice of sleep time may have confounded the theory. Watch changeover days had the worst sleep in terms of fragmentation. This is not surprising given that the participants would be attempting to sleep at an inappropriate circadian phase, particularly during the change from 1200-1600/2400-0400 h to 1600-2000/0400-0800 h.

Partial suppression of melatonin secretion by light exposure at night may well have occurred during the night watches in 24-h daylight (particularly the watch of 1200-1600/2400-0400 h) and may have skewed the calculated phase. However, complete suppression was not observed, and there were no significant differences overall in amplitude between the watches; large individual variation in amplitude was evident (Fig. 3). With darkness at night, lighting on the bridge was kept very dim to maintain the watch keepers' night vision.

Shorter sleep in the 1st week of the voyage (both crews) was associated with poor weather as previously described (for a review, see Smith et al., 2001). Interestingly, light at night appeared to improve sleep slightly; however, there were insufficient data to determine whether this was related to better circadian adaptation or other factors. A minor increase in sleep duration in the 1st crew (in the main sleep) compared to the 2nd crew may be owing to younger average age. The 1st crew, aged  $32.2 \pm 9.2$  years, was significantly younger than the 2nd crew, aged  $41.9 \pm 10.1$  years ( $p < 0.05$ ).

The present data reinforce the observations of Howarth et al. (1999) that although fixed watch keepers may have short sleep, the quality of sleep is if anything better than that of day workers. It is the weekly change of watches that is likely to be the major factor in the poor sleep of rotators. Sleep deprivation and circadian desynchrony are associated with numerous health risks, lowered alertness and performance, and an increased accident rate (e.g., Moore-Ede and Richardson, 1985; Rajaratnam and Arendt, 2001). Unless there are very good reasons for maintaining

rotating watches, we consider that health and safety would best be served by operating fixed watches. This is particularly pertinent for ships operating busy routes and in ice, in which extreme vigilance of watch keepers is required.

## ACKNOWLEDGMENTS

We would like to acknowledge funding from the Antarctic Funding Initiative (project No. CGS 4/09, British Antarctic Survey), Stockgrand Ltd., University of Surrey, Cambridge Neurotechnology for the loan of the AWLs, all the willing and cheerful volunteers, Captain J. B. Marshall, Captain G. Chapman, and particularly Captain S. Lawrence for the original suggestion.

## REFERENCES

- Akerstedt T, Gillberg M, and Wetterberg L (1982) The circadian covariation of fatigue and urinary melatonin. *Biol Psychiatry* 17:547-554.
- Aldhous ME and Arendt J (1988) Radioimmunoassay for 6-sulphatoxymelatonin in urine using an iodinated tracer. *Ann Clin Biochem* 25:298-303.
- Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, and Pollack CP (2003) The role of actigraphy in the study of sleep and circadian rhythms. *Sleep* 26:342-392.
- Barnes RG, Forbes MJ, and Arendt J (1998) Shift type and season affect adaptation of the 6-sulphatoxymelatonin rhythm in offshore oil rig workers. *Neurosci Lett* 252:179-182.
- Bojkowski CJ, Arendt J, Shih MC, and Markey SP (1987) Melatonin secretion in humans assessed by measuring its metabolite, 6-sulphatoxymelatonin. *Clin Chem* 33:1343-1348.
- Cole RJ, Kripke DF, Gruen W, Mullaney DJ, and Gillin JC (1992) Automatic sleep/wake identification from wrist activity. *Sleep* 15:461-469.
- Colquhoun WP (1985) Hours of work at sea: watchkeeping schedules, circadian rhythms and efficiency. *Ergonomics* 28:637-653.
- Condon R, Colquhoun P, Plett R, Knauth P, Fletcher N, and Eickhoff S (1986) Circadian variation in performance and alertness under different work routines on ships. In *Night and Shiftwork: Long-term Effects and Their Prevention*, Haider M, Koller M, and Cervinka R, eds, pp 277-284, Verlag Peter Lang, Frankfurt, Germany.
- Folkard S (1997) Black times: temporal determinants of transport safety. *Accid Anal Prev* 29:417-430.
- Gibbs M, Arendt J, Morgan L, and Hampton S (2004) *Circadian Adaptation, Dietary Intake and Metabolic Responses in Offshore Shiftworkers*. Offshore Technology Report, UK, Health and Safety Executive. Available from: <http://www.hse.gov.uk/research/otopdf/2000/oto0012>.
- Howarth HD, Pratt JH, and Tepas DI (1999) Do maritime crew members have sleep disturbances? *Int J Occup Environ Health* 5:95-100.
- Kelly TL, Neri DF, Grill JT, Ryman D, Hunt PD, Dijk DJ, Shanahan TL, and Czeisler CA (1999) Nonentrained circadian rhythms of melatonin in submariners scheduled to an 18-hour day. *J Biol Rhythms* 14:190-196.
- Knutsson A and Boggild H (2000) Shiftwork and cardiovascular disease: review of disease mechanisms. *Rev Environ Health* 15:359-372.
- Leger D, Guilleminault C, Santos C, and Paillard M (2002) Sleep/wake cycles in the dark: sleep recorded by polysomnography in 26 totally blind subjects compared to controls. *Clin Neurophysiol* 113:1607-1614.
- Lockley SW, Skene DJ, and Arendt J (1999) Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. *J Sleep Res* 8:175-183.
- Lowden A, Akerstedt T, and Wibom R (2004) Suppression of sleepiness and melatonin by bright light exposure during breaks in night work. *J Sleep Res* 13:37-43.
- Moore-Ede MC and Richardson GS (1985) Medical implications of shift-work. *Annu Rev Med* 36:607-617.
- Parkes KR, Clark MJ, and Payne-Cook E (1997) *Psychosocial Aspects of Work and Health in the North Sea Oil and Gas Industry, Part III: Sleep, Mood and Performance in Relation to Offshore Shift Rotation Schedules*. Publication No. OTH 96 530. Oxford, UK: Health and Safety Executive.
- Rajaratnam SM and Arendt J (2001) Health in a 24-h society. *Lancet* 358:999-1005.
- Roberts SE and Hansen HL (2002) An analysis of the causes of mortality among seafarers in the British merchant fleet (1986-1995) and recommendations for their reduction. *Occup Med (Lond)* 52:195-202.
- Rutenfranz J, Plett R, Knauth P, Condon R, De Vol D, Fletcher N, Eickhoff S, Schmidt KH, Donis R, and Colquhoun WP (1988) Work at sea: a study of sleep, and of circadian rhythms in physiological and psychological functions, in watch keepers on merchant vessels, II: sleep duration, and subjective ratings of sleep quality. *Int Arch Occup Environ Health* 60:331-339.
- Schernhammer ES, Laden F, Speizer FE, Willett WC, Hunter DJ, Kawachi I, and Colditz GA (2001) Rotating night shifts and risk of breast cancer in women participating in the nurses' health study. *J Natl Cancer Inst* 93:1563-1568.
- Smith A, Lane T, and Bloor M (2001) *Fatigue Offshore: A Comparison of Offshore Oil Support Shipping and the Offshore Oil Industry*. Wales, UK: Cardiff University Press, Seafarers International Research Centre.
- Smith L, Folkard S, and Poole CJ (1994) Increased injuries on night shift. *Lancet* 344:1137-1139.
- Ware J (1985) Linear models for the analysis of several measurements in longitudinal studies. *Am Stat* 39:95-101.