International Journal of Occupational Safety and Ergonomics (*JOSE*) 2010, Vol. 16, No. 4, 487–496

Offshore Fleet Workers and the Circadian Adaptation of Core Body Temperature, Blood Pressure and Heart Rate to 12-h Shifts: A Field Study

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Objectives. *The aim of this study was to investigate the circadian adaptation of* t_{cr} *(core body temperature), BP (blood pressure), HR (heart rate) and subjective sleep quality after 7 days of working 12-h night shifts in offshore fleet workers.* ***Methods.*** *Night workers (*N = 7*) (18:00–6:00) and day workers (*N = 7*) (6:00–18:00) were recruited from a Norwegian offshore company operating in the North Sea. We measured* t_{cr}*, BP and HR on days 1 and 7.* ***Results.*** *An increase of 0.6* ^{o}*C (*p = .03*) was observed within the group of night workers from day 1 to day 7. Between the night and day workers there was a significant difference of 0.6* ^{o}*C from day 1 to day 7 (*p = .01*). Sleep latency and sleep length also showed significant differences between the groups (*p = .01 *and* p = .04*). There was an interaction effect in tiredness during the shift (*p = .02*).* ***Conclusion.*** *The significant increase in* t_{cr} *indicates an adaptation in the night workers to the new working schedule, and the extended working hours and sleep deprivation are hypothesized to be the main cause of the increased* t_{cr}*. Light exposure, altered pattern of food availability and physical activity are likely to have contributed as well. Subjective sleep quality showed inconclusive results.*

offshore fleet   circadian rhythms   blood pressure   heart rate   core temperature

1. INTRODUCTION

Advanced technology has rationalized and simplified vessel to rig operations at sea. Night work is not a natural schedule for humans and it causes a desynchronization of circadian rhythms from the external environment. Rapid adaptation to night work is therefore crucial, since circadian desynchronization compromises safety [1, 2]. External stimuli such as vessel motion [3], noise [4, 5] and low light exposure [6] are common complaints in sailing personnel and these have been known to affect the adaptation to new working schedules and subjective quality of sleep [6]. Offshore fleet workers are, in contrast to other sailing personnel and onshore workers, particularly exposed to these stimuli since they perform complex marine operations on a 24-h basis in a

We wish to thank the offshore workers of Farstad Shipping, Acergy Norway and SMC for their participation in this study, which would not have been possible without their co-operation.

Special thanks are due to ship's medic Jan Skodvin for his help and support with the data collection.

The Norwegian Research Council supported the study with grant 180165/140.

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more extreme environment. This may result in a slower adaptation to the working schedule.

There are cyclic circadian patterns in core body temperature (t_{cr}), blood pressure (BP) and heart rate (HR) [7, 8, 9, 10, 11, 12]. Shift workers have been shown to shift the rhythm of t_{cr} [13, 14] and sailors on oil tankers showed a later rhythm peak (acrophase) of t_{cr} in night workers [15]. More specific studies of 12-day simulated sea-watches (22:00–6:00) [16] showed that oral temperature decreased from 36.6 to 36.1 ºC on the 22:00–6:00 shift during the first 3 days. On days 10–12, the temperature remained relatively stable at 36.6 ºC during the whole shift. Another study shower that BP was significantly elevated during 12-h night shifts in onshore conditions [17, 18], whereas HR as measured in sailors showed variations that were mainly determined by activity and sleep [19]. It is unknown how these parameters behave in offshore vessel workers in field conditions.

Since no field studies of t_{cr}, BP and HR have been performed in offshore vessels workers and considering the extreme working conditions that may affect the adaptation to night shifts, it is important to investigate this in further detail. More research is needed to improve and ensure optimal procedures for shift workers in the offshore fleet. To ensure safe operations at sea, it is also essential to learn how the external stimuli affect offshore fleet workers in field conditions, this in terms of changes in (a) t_{cr}, BP and HR and (b) subjective sleep quality.

Hypothesis

Offshore fleet workers who change their wake/sleep pattern from day to night shifts will adapt slower to the changed working schedule compared to other sailing and onshore personnel. The following outcomes are predicted after 7 days of night work:

- An increase in t_{cr}, BP and HR. The increases are predicted to be lower than those in other sailing and onshore personnel working shifts. The group working day shifts will not show any changes.
- Subjective sleep quality as measured by sleep diaries will show significant improvement.

2. METHOD AND MATERIALS

2.1. Subjects

Two groups of healthy subjects on night and day shifts were studied. The subjects on the night shift (n = 7) consisted of 6 males and 1 female ranging in age 24–46 years (33 ± 8), body mass 75–95 kg (84 ± 8) and height 174–191 cm (179 ± 6). The subjects on the day shift (n = 7) were all males 22–46 years old (29 ± 9), with body mass of 60–103 kg (89 ± 15) and 172–198 cm tall (183 ± 9). The subjects were recruited from crews on an offshore vessel operating in the North Sea. All subjects gave informed consent in writing and the Regional Committee for Medical and Health Research Ethics in Trondheim, Norway, approved the procedures for the protocol. Prior to going offshore the subjects underwent a medical examination and were approved by a licensed naval doctor. They worked 12-h shifts in different positions on the vessel, in which the night shift worked 18:00–6:00 and the day shift worked 6:00–18:00. The subjects were on 14-day or one-month duty rotas, depending on the contractor concerned. Their tour of duty started on the same date and time. There were no significant differences in age, weight or height in the two groups at study start.

2.2. Temperature Measurement

Body temperature was measured with a LighTouch LTX ear thermometer (Exergen, USA). The thermometer measures the arterial temperature via an algorithm based upon radiation from the tympanic membrane (t_{ty}) (°C), which receives its vascularisation from the arteria carotis interna. The LighTouch LTX has been validated as a valid instrument for measuring t_{cr} [20]. Although t_{cr} has no clear definition, it is generally regarded as inner body temperature or the temperature of the vital organs including the brain [21]. The pulmonal artery is considered to be the most representative location of the core temperature [22] and studies show a strong correlation (r = .96) between t_{ty} and pulmonary arterial temperature (t_{pa}) [20, 23]. In this study we used t_{ty} as a measure of t_{cr}.

2.3. BP and HR

BP was measured with an Omron M6® blood pressure measuring device (Omron Healthcare, Japan). This device has been validated in several studies [24, 25, 26]. If irregular pulses are detected, they are indicated. HR measurements took place at the same time as the BP measurements.

2.4. Actigraphy

The subjects were fitted with an accelerometer from ActiGraph (ActiGraph LLC, USA) to monitor their rest/activity pattern. It was recently named as the most accurate commercially available accelerometer on the basis of a review of eight different accelerometers [27]. The accelerometer was set to measure motor activity at one-minute intervals, which is the recommended interval for rest/activity pattern [28]. The output is in the form of average counts per minute (ACM). Reviewing the ACM thus provides an estimate of the rest/activity pattern in that period. The data were summarized in a 30-min time epoch prior to the physiological measurements to evaluate the effect of activity on the physiological parameters.

2.5. Sleep Diary

Subjective sleep quality was estimated from entries in a modified sleep diary based on elements from the Karolinska sleep diary [29]. The sleep diary is used to reflect typical disturbances in initiating and maintaining sleep, as well as a global appreciation of sleep [30]. The variables in the questionnaire were split into three sections; in section 1 the questions asked were Bedtime? (h), When did you try to sleep? (h), Sleep latency? (h), Time of awakening? (h), Out of bed? (h) and Sleep length? (h). The question of when they tried to sleep was asked to get a more accurate estimate of actual sleep time since some workers would read or watch videos before trying to sleep. In section 2, the questions asked were How did you sleep? (5—*very well*, 1—*very poorly*), Feeling refreshed after awakening? (5—*completely*, 1—*not at all*), Calm sleep? (5—*very calm*, 1—*very restless*), Slept through the time allotted? (5—*yes*, 1—*woke up to early*), Ease of awakening? (5—*very easy*, 1—*very difficult*), Ease of falling asleep? (5—*very easy*, 1—*very difficult*) and Amount of dreaming? (5—*many*, 1—*none*). In section 3 the questions asked were Extra naps during time off? (number of naps), Caffeinated drinks? (number of caffeinated drinks) and How tired did you feel during the shift? (5—*very tired*, 1—*not tired at all*). The data from the sleep diary were summarized on all the variables to evaluate their day-to-day evolution and to test significant changes from day 1 to day 7.

2.6. External Measurements

Light intensity (lux) was measured with an LMT pocket lux 2 standard luxmeter (LMT Lichtmesstechnik, Germany). It measures from 0 to 100 000 lx. Vessel motion was measured with the onboard motion registration unit, which measures wind direction and wind speed every 2 h and logs the data in the ship's computer. The data refer to the Beaufort scale. Noise (decibels) was measured with a Brüel & Kjær 2250 sound-level meter (Brüel & Kjær 2250 Light, Denmark). This instrument has a 16.4–120 dB dynamic measuring range that measures at 120-ms intervals. Light intensity and noise were measured at eye level in the centre of the work area, to be as representative as possible. The measurements were performed at the same time as the t_{cr}, BP and HR in the working areas, e.g., the remotely operated vehicle (ROV) operator room, the ROV workshop and the bridge.

2.7. Testing Procedures

The first series of t_{cr}, BP and HR measurements were performed on the first shift of both groups (day 1). Since the work tasks on the vessel required the participants to be at their workstations at most times, the study co-ordinators went to the work areas to make the measurements. The t_{cr} was measured according to the instruction manual for the LighTouch LTX ear thermometer. The BP measurements were carried out following a standardized method, according to the American Heart

Association recommendations for blood pressure measurement in humans and experimental animals [31]. The measurements were performed twice during the last 6 h of each shift, although we had to take the nature of the specific offshore operation into consideration, e.g., waiting time, delays, stress factor. Thus there were deviations in the time of measurement on day 1 and day 7, but we aimed to perform the measurements at the same time to compare the data on the two measurement days.

2.8. Statistical Analysis

The data were analysed with SPSS for Windows version 16.0 and Microsoft Office Excel 2003. Distributions were assessed using Q-Q plots and one sample Kolmogorov–Smirnov tests. Paired samples *t* tests were used to compare between day 1 and day 7 within each group, and *t* tests for independent samples were used to compare between the night and day workers. Delta values (Δ) were calculated to compare between groups. The sleep diary was analysed with analysis of variance (ANOVA) repeated measures. All results were considered to be statistically significant at $p < .05$.

3. RESULTS

3.1. Physiological Parameters

There was an increase in t_{cr} of 0.6 °C (p = .03) within the night workers' group from day 1 to day 7 at testing times 4:19 and 4:23 (Table 1, Figure 1). There was also a significant difference in t_{cr} of 0.6 °C between the night workers (Δ at 4:19–4:23) and day workers (Δ at 15:38–15:16) from day 1 to day 7 (p = .01). Some measurements were missing in both groups during day 1 and

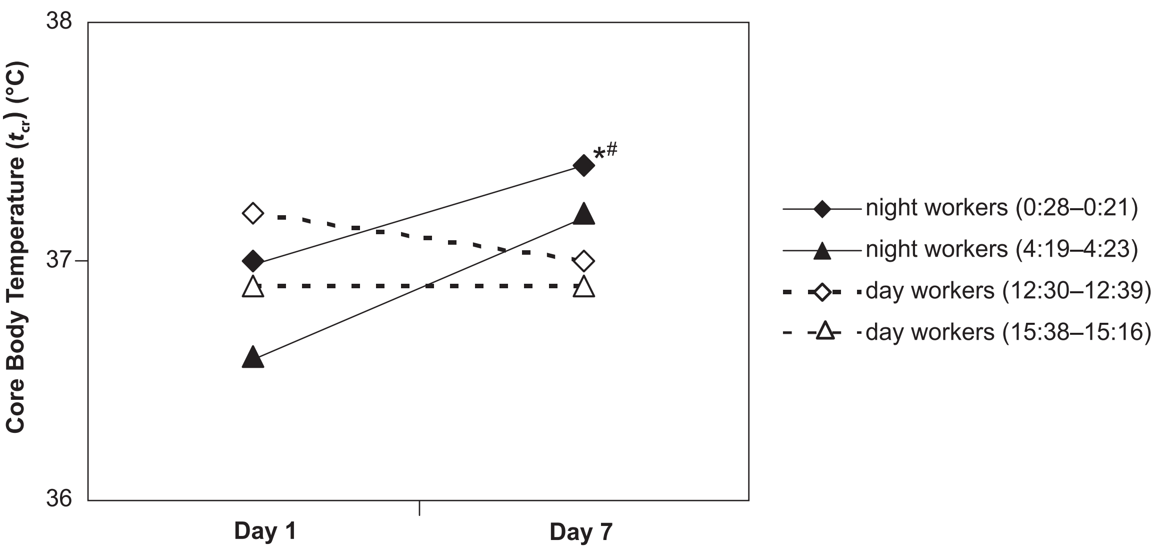

Figure 1. Changes in core body temperature (t_{cr}) from day 1 to day 7. *Notes.* *—significant within night workers at 4:19–4:23 ($p < .05$); #—significant within night workers (Δ values at 4:19–4:23) and day workers (Δ values at 15:38–15:16) ($p < .05$).

TABLE 1. Physiological Parameters (*M* ± *SD*)

		Day 1					Day 7				
Workers	***N***	**Time**	**t_{cr}**	**SYS BP**	**DIAS BP**	**HR**	**Time**	**t_{cr}**	**SYS BP**	**DIAS BP**	**HR**
Night	6	0:28 ± 0:16	37.0 ± 0.6	121 ± 7	82 ± 12	66 ± 10	0:21 ± 0:26	37.4 ± 0.6	127 ± 10	78±6	66 ± 8
	5	4:19 ± 0:21	36.6 ± 0.5	121 ± 12	78 ± 14	65 ± 5	4:23 ± 0:24	37.2 ± 0.4*#	132 ± 16	84±9	65 ± 5
Day	5	12:30 ± 0:18	37.2 ± 0.5	119 ± 5	80 ± 11	69 ± 4	12:39 ± 0:31	37.0 ± 0.4	129 ± 14	82±6	69 ± 9
	6	15:38 ± 0:28	36.9 ± 0.5	121 ± 13	78 ± 9	65 ± 10	15:16 ± 0:11	36.9 ± 0.3	121 ± 8	70±15	63 ± 5

Notes. *—significant within the night workers at 4:19–4:23 ($p < .05$); #—significant between the night workers (Δ at 4:19–4:23) and day workers (Δ at 15:38–15:16) ($p < .05$); t_{cr}—core body temperature (°C), SYS BP—systolic blood pressure (mmHg), DIAS BP—diastolic blood pressure (mmHg), HR—heart rate (beats/min).

day 7 due to the operational activity on the vessel (see *N* in Table 1).

3.2. Sleep Diary

Sleep latency was on average shorter in the night workers (0:07 ± 0:03) compared to the day workers (0:16 ± 0:04) (p = .01). Average sleep length was longer in the night workers (7:30 ± 0:20) compared to the day workers (6:32 ± 0:36) (p = .04). The question How tired did you feel during the shift? showed a significant interaction effect in the night workers (4.3 ± 0.8 to 1.7 ± 0.7) and in the day workers (2.8 ± 1.3 to 3.0 ± 1.0) (p = .02) thus indicating a different pattern of adaptation. The analysis of the sleep diary was based on 6 night workers and 5 day workers due to inadequate questionnaire data.

3.3. Actigraphy

The data from the accelerometers showed no significant changes in ACM between day 1 and day 7 within or between the groups.

3.4. External Measurements

3.4.1. Light exposure

The night-shift group were generally exposed to a range of 3–243 lx and the dayshift to between 72 and 6126 lx in their working areas. During the day the port at the stern of the ship was open, permitting strong sunlight to enter the working areas. It is possible that moonlight could have increased the amount of light exposure to the night workers, but at night this port was often closed. The lighting conditions between day 1 and day 7 for the night-shift workers were constant, since the light exposure in the ship's compartments were exactly the same all night. Sunrise on day 1 was at 5:39 and sunset at 21:34. On day 7, sunrise was at 5:18 and sunset at 21:55.

3.4.2. Vessel motion

The average wind speed ranged from 1.66 to 5 (p = .004) on the Beaufort scale during the 7 days at sea. However, accelerometers placed strategically on the bridge and at the sleeping quarters did not register any change in vessel motion.

3.4.3. Noise

The night-shift workers were exposed to average noise levels of 65 ± 6 dB and the day-shift ones to levels of 65 ± 5 dB. There were no statistical differences between day- and night-shift noise levels.

4. DISCUSSION

This study showed a significant increase in t_{cr} from day 1 to day 7 of 0.6 ºC (p = .03) in the night workers and of 0.6 ºC between the night and day workers (p = .01). Our main finding is that working on the night shift alters the circadian timing of t_{cr} and that this is related to the working hours. The day workers did not show any significant changes and showed identical developments on day 1 and day 7 during the course of the shift.

No studies currently exist that measure rectal temperature (t_{re}) or t_{ty} in sailors and at present oral temperature is the best studied parameter. Since oral temperature can be predicted from t_{ty} with a mean difference of –0.2 ºC [32, 33] the changes in temperature in other studies of sailors can be used as a basis of comparison. Our results confirm the findings in sailors [15] and Colquhoun, Blake and Edwards's studies of 8-h watches (22:00–6:00), which showed a 0.5 ºC increase in oral temperature [16] and of 4-h watches (12:00–16:00/0:00–4:00) which showed a 0.3 ºC increase in oral temperature [34]. It is clear from these data that longer continuous watches, such as 10- or 12-h watches, facilitate a larger increase in oral temperature and t_{cr} at night time. The displacement in working hours is probably an event that has the greatest influence on performance and human circadian physiology [35, 36]. Since our study participants had longer waking hours due to the longer night shift, it is possible that this caused the larger increase in t_{cr}. Thus it seems that organization and the length of the shift are the decisive factors for the increase in t_{cr}.

The results from the Karolinska sleep diary indicate that subjective sleep quality is affected differently depending on the working hours. An interesting result is that sleep latency is shorter in the night workers. The most logical explanation for this is that most likely the sleep-deprived night workers were more fatigued and thus were able to initiate sleep faster.

Longer sleep in the night workers compared to the day workers may at first be due to recuperating sleep to make up for the extended working hours at day 1. It is expected that the circadian sleep drive would affect the daytime sleep compared to the day workers, but this could not be determined since no sleep fragmentation was recorded. However, since the tiredness during the shift across the days improved, the sleep evidently provided a reduction in tiredness.

External stimuli such as light exposure is a most potent circadian synchronizer and it is well-established that the solar light–dark cycle is the primary environmental time cue for most living organisms [37]. Badia, Myers, Boecker, et al. were among the first to demonstrate an effect of bright light (5 000 lx) on nocturnal t_{cr} [38]. In an experimental procedure they were able to show that t_{cr} dropped sharply under dim light but only slightly under bright light, suggesting that light intensity was a strong modulator of t_{cr}. Kubota, Uchiyama, Suzuki, et al. found that t_{cr} was phase-delayed by 1.12 h as a response to 5 h of 5 000 lx light exposure between 0:00 and 5:00 [39]. In view of these earlier studies, exposure to light during the nightly working hours may have been a contributing factor to the observed change in t_{cr}.

Food intake has also been shown to be a powerful synchronizer of the suprachiasmatic nucleus (SCN) [40, 41]. Since t_{cr} is controlled by the SCN, alterations in t_{cr} are likely to reflect changes in the circadian clock. The ship's galley served meals round the clock to meet the demands of both shifts. Mealtimes for the night- and day-shift workers were similar relative to their 12-h watch, i.e., a meal at the start of the shift, a meal after 6 h and a meal after 12 h at the end of the shift. For the night-shift workers, this meant having a full supper between 23:30 and 24:00. Although the composition of the meals served during the voyage was not registered, they usually consisted of a meat dish with a selection of vegetables and a sauce. Eating a meal initiates a whole sequence of enzymatic reactions and a diet-induced thermogenesis [42]. Since the thermal effects of food generally reach a maximum one hour after a meal and because circadian cycles have been shown to synchronize with food availability [43], meal times and the composition of each meal may have been significant factors in the increased t_{cr}.

Physical activity raises t_{cr} due to muscular activity and thus heat production [42]. Although the workers in this study did not perform hard physical work one should keep in mind that light activities such as walking or running lightly only utilizes 20–25% of the energy expenditure for mechanical effort and the remaining for heat production [42]. Since no significant changes in activity were found between measurement days, it is unlikely that this contributed to the increased t_{cr}.

Noise levels did not attain the threshold values laid down by the Norwegian Maritime Directorate [44]. We therefore excluded them as a decisive factor for the adaptations observed.

We hypothesized that we would find significant differences in BP and HR, but this did not occur. Since BP and HR remained unchanged after 7 days of working night shifts, we can either conclude that the circadian drive does not significantly affect HR and BP or that the higher activity level at night is the main modulator. Both factors are likely to be true as stated by other authors [19, 45]. Since BP or HR were recorded during sleep, we cannot predict if the change in working hours influenced them under their subjective night.

Hansen, Geving and Reinertsen's field study of offshore vessel workers showed that offshore vessel workers adapted slower to 12-h night shifts compared to their colleagues on oil rigs on similar schedules [46]. This was measured with sulphatoxymelatonin (aMT6s). Since aMT6s and t_{cr} are inversely coupled [47, 48] the offshore vessel workers are likely to have a slower adaptation also of t_{cr}, but currently there are no studies of t_{cr} in offshore oil rig workers. Also studies of subjective sleep quality in offshore oil rig workers in the North Sea showed faster adaptations rates compared to offshore vessel workers [49, 50]. Furthers research into the adaptation of t_{cr} in offshore oil rig workers would therefore serve as an exciting new line of future research to make comparisons to offshore vessel workers.

5. CONCLUSIONS

This study is the first to investigate the change in t_{cr}, BP and HR in this particular group of offshore workers under realistic working conditions. The t_{cr} increased significantly by 0.6 ^{o}C from day 1 to day 7 within the night workers and compared to the day workers. BP and HR showed no significant changes. The significant increase in t_{cr} indicates an adaptation in the night workers to the new working schedule, and the extended working hours and sleep deprivation are hypothesized to be the main cause of the increased t_{cr}. Light exposure, altered pattern of food availability and physical activity are likely to contribute as well. Our hypothesis of a smaller adaptation in offshore vessel workers showed under the circumstances not to be true, but direct comparisons of 12-h shifts in sailors and offshore workers may have yielded other results.

Subjective sleep quality showed a trend towards adaptation in the night workers, but the results were not as conclusive as other studies of offshore workers. As expected, the day workers did not experience any changes in subjective sleep quality.

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