

Shift rotation, overtime, age and anxiety as predictors of offshore sleep patterns

Katharine R Parkes

University of Oxford, UK

University of Western Australia

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Department of Experimental Psychology,

University of Oxford,

South Parks Road,

Oxford, OX1 3UD, England

Tel. +44 1865 271444

Fax +44 1865 271310

e-mail: kathy.parkes@psy.ox.ac.uk

Abstract

Shift work on offshore oil/gas installations necessitates 12 h shifts and rapid day/night shift changes. In the North Sea, both 'fixed shift' (alternate day-shift and night-shift tours) and 'swing-shift' rotations (with a mid-tour shift change) are operated. The present study used survey data (N=775) to examine sleep patterns over three 'phases' of the offshore work cycle (day shifts, DS; night shifts, NS; and leave weeks, LS) in relation to shift roster, overtime, age, offshore shift work exposure, and anxiety. Specific predictions were tested in a mixed-model ANOVA in which DS, NS, and LS sleep were treated as repeated measures.

Sleep duration and sleep quality were predicted by significant interactions of phase with roster, anxiety, age, and shift work exposure, but the patterns of findings differed across DS, NS and LS. Consistent with other published findings, personnel working two-week nights-to-days swing shifts reported shorter DS and NS sleep duration than those working fixed shifts. Extended 3-week tours (7 nights/14 days) showed an advantage only for DS sleep. There was no evidence that LS sleep was impaired following night-shift work. Overtime was negatively related only to NS sleep duration. Anxiety predicted poor NS and DS sleep; the relationship between age and NS sleep quality was curvilinear with minimum values at 38-42 y. Shift work exposure negatively predicted NS (but not DS or LS) sleep. The results are discussed in relation to the initial predictions; more general implications of the findings, and methodological limitations of the work, are considered in a final section.

KEY WORDS: Day/night shifts; shift work exposure years, long work hours; overtime; individual differences

The remote locations of North Sea oil/gas installations necessitate extended work rosters, and the limited accommodation on board requires that continuous production and drilling operations are maintained with only two crews. Thus, UK offshore personnel typically work 12 h shifts for two successive weeks, followed by a shore break of two or three weeks (although longer tours may be worked in more distant locations) and, not infrequently, the basic 84 h work week is further extended by overtime hours (Härmä, Sallinen, Puttonen, Salminen, & Hublin, 2007). These intensive shift patterns are worked in an environment that combines hazardous production processes, safety critical tasks, and a wide range of physical and psychosocial stressors, including unpredictable sea and wind conditions, noise, vessel motion, heavy manual work, time pressures, and constrained living and working space (e.g. Gardner, 2003; Haward, Lewis, & Griffin, 2009; Niven & McLeod, 2009). Thus, offshore personnel are exposed to both operational risks (e.g. explosion or fire) (e.g. Bjerkan, 2010; Deacon, Amyotte, & Khan, 2010; Vinnem, 2010) and individual health risks (e.g. injury, illness, low morale) (e.g. Ljoså, Tyssen, & Lau, 2011; Ponsonby, Mika, & Irons, 2009; Parkes, 1999).

The duration and quality of sleep play a vital role in mitigating these risks. Numerous studies of sleep, and its impact on fatigue, performance and safety among onshore shift workers, have been reported, and several reviews published (e.g. Driscoll, Grunstein, & Rogers, 2007; Saksvik, Bjorvatn, Harvey, Waage, Harris et al., 2011a; Wagstaff & Lie, 2011); however, research into offshore shift work has not received the same level of attention. The present paper seeks to extend the existing literature by examining the sleep patterns reported by North Sea shift workers in relation to four different rotation rosters operated on UK offshore installations, whilst also taking into account overtime work and individual differences.

Offshore Shift Rotation

The majority of North Sea personnel work either permanent day shifts or rotating day/night shifts over two-week tours (Hope, Øverland, Brun, & Matthiesen, 2010; Parkes, 2012). Shift rotation offshore is scheduled either as '*fixed-shift*' rosters in which 14 day shifts (designated 14D) and 14 night shifts (14N) alternate on successive tours, or as '*swing shift*' rosters in which 7 day shifts and 7

night shifts are worked during each tour¹. Swing-shift patterns usually take the form of a night-shift week followed by a day-shift week (7N/7D), although the reverse order (7D/7N) is used on some installations. Three-week tours, which are less common, usually involve a change of shift at the end of the first week (7N/14D).

Research carried out in offshore work settings demonstrates adverse effects of rapid shift changes, particularly the 7N/7D swing-shift schedule which involves two 12 h circadian changes during a two-week offshore tour. Although full adaptation to night-shift work during the initial offshore week takes place in 5-6 days (Barnes, Deacon, Forbes, & Arendt, 1998), evidence shows that re-adaptation to day shifts is rarely complete during the second week (Gibbs, Hampton, Morgan, & Arendt, 2007; Harris, Waage, Ursin, Hansen, Bjorvatn et al., 2010). Thus, impaired sleep and alertness persist for all or most of the day-shift week (Bjorvatn, Stangenes, Øyane, Forberg, Lowden et al., 2006; Parkes, Clark, & Payne-Cook, 1997; Saksvik et al., 2011a; Waage, Harris, Pallesen, Saksvik, Moen et al., 2012). In contrast, when fixed-shift 14N rosters are worked, sleep patterns remain fully adjusted during the second offshore week (Gibbs et al., 2007; Harris et al., 2010), but circadian re-adaptation occurs during shore leave, thus disrupting normal social and family activities.

Considered together, these field studies reveal a complex picture of circadian adaptation and shift rotation offshore, but they are in general agreement in showing that the 7N/7D roster has adverse effects on sleep and alertness during both offshore weeks, and that night-shift adaptation occurs more quickly than re-adaptation to a normal diurnal cycle (for a review, see Parkes, 2012). However, such studies have several limitations; thus, intensive data collection restricts sample sizes (usually to 8-30 participants), typically only one occupational group is included, and data collection covers only standard 12 h shifts, disregarding possible overtime. Thus, the findings may not adequately represent offshore shift workers more generally.

Survey studies provide one way of extending information about the sleep patterns of North Sea workers to larger and more representative samples, thus complementing the findings of small-scale

¹ The terms 'fixed-shift' and 'swing-shift' used in this paper are specific to the offshore environment; they are widely used by offshore oil industry personnel, and in the related research literature, to identify the two different day/night rotation patterns described.

field studies. However, most offshore survey research in this area is cross-sectional and therefore does not permit causal interpretation of relations between shift patterns and sleep measures. Onshore, shift workers typically report more sleep impairment than their day-work counterparts (Åkerstedt, 2003; Sallinen & Kecklund, 2010; Wright, Bogan, & Wyatt, 2013); this finding also applies offshore, and remains significant when potential confounding factors (e.g. occupational and demographic characteristics) are taken into account (e.g. Menezes, Pires, Benedito-Silva, & Tufik, 2004; Parkes, 1999; Waage, Moen, & Bjorvatn, 2010).

As night work is essential in the North Sea oil/gas industry, the extent to which different shift rosters impact on the sleep of offshore personnel, and the identification of optimum rotation patterns, is arguably more important than overall comparisons of day work and shift work. Survey research relating sleep to shift rotation patterns has been carried out in onshore settings (e.g. Flo, Pallesen, Åkerstedt, Mageroøy, Moen et al., 2013) but only rarely offshore. Exceptions include a report by Lauridsen, Tronsmoen, Berland, Gitlesen, Ringstad et al. (1991) and, more recently, inclusion of shift rotation as a control variable in a study of sleep quality offshore (Hope et al., 2010). However, in neither case were separate measures used to assess sleep during day-shift and night-shift work. Existing survey findings thus provide little information about the extent to which different offshore shift rotations impact on day-shift and night-shift sleep. In addition, few survey studies have included assessment of sleep during shore breaks although evidence suggests that sleep duration during leave weeks is about 1 h longer than during offshore weeks (Parkes, 1994; Parkes, 2002).

Moreover, although overtime is not unusual on North Sea installations², it has been largely disregarded in studies of offshore shift work. However, in onshore research, significant associations between overtime and adverse sleep outcomes, including reduced sleep duration, have been reported (Dahlgren, Kecklund, & Åkerstedt, 2006; Nakashima, Morikawa, Sakurai, Nakamura, Miura et al., 2011); there is also evidence that long work hours and night work interact to predict impaired sleep and severe sleepiness at work (Son, Kong, Koh, Kim, & Härmä, 2008). The lack of information about

² Lodden, T. (2000). *The effect on the health and safety of older offshore personnel - Long shifts and working night shift*. Paper presented at the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Stavanger, Norway. 26-28 June 2000. Society of Petroleum Engineers, SPE 60997.

the extent and consequences of overtime work offshore contrasts with the view that overtime on North Sea installations merits special attention, as it not only extends the standard 84 h work week but also increases the risk of exposure to chemical and other hazards (Härmä et al., 2007).

Individual and environmental factors influencing sleep-wake patterns in shift work

The empirical findings outlined above, and the disruptive effects of shift work on sleep more generally, derive from two physiological processes: (i) the homeostatic drive for sleep (which rises with increasing time awake and falls with increasing time asleep), and (ii) the cyclical circadian rhythm by which functions such as body temperature, activity, sleep propensity and alertness, rise and fall with time of day (e.g. Åkerstedt & Wright Jr, 2009; Dijk & Franken, 2005). Whilst these processes provide a physiological basis for understanding of patterns of sleep/wakefulness, more complex models of shift work also include person and environment characteristics as potential influences on sleep (e.g. Härmä, 1993; Saksvik, Bjorvatn, Hetland, Sandal, & Pallesen, 2011b; Smith, Robie, Folkard, Barton, Macdonald et al., 1999) and associated performance impairment and accident risk (Van Dongen & Belenky, 2009; Williamson, Lombardi, Folkard, Stutts, Courtney et al., 2011).

These models accord with findings linking impaired sleep to particular socio-demographic characteristics (e.g. higher age, female gender, and managerial/professional occupations) (e.g. Hope et al., 2010; Marquie & Foret, 1999; Takahashi, Tsutsumi, Kurioka, Inoue, Shimazu et al., 2014); task attributes (e.g. monotony and heavy physical work) (Sadeghniiat-Haghighi, Yazdi, Jahanihashemi, & Aminian, 2011; Williamson et al., 2011); longer exposure to shift work (Marquie & Foret, 1999; Tucker, Folkard, Ansiau, & Marquié, 2011); and individual differences, such as ‘eveningness’ chronotype and negative affectivity (for a review, see Saksvik et al., 2011b). Circadian type may also interact with shift patterns to predict sleep-related outcomes (Juda, Vetter, & Roenneberg, 2013; Natvik, Bjorvatn, Moen, Magerøy, Sivertsen et al., 2011; Storemark, Fossum, Bjorvatn, Moen, Flo et al., 2013).

Among offshore shift workers, two individual difference variables, anxiety and age, merit particular attention in relation to sleep. In the general population, anxiety is associated with impaired sleep (e.g. Strine & Chapman, 2005), and it has also been linked to the tendency to constantly monitor the environment for signs of threat (Voss, Kolling, & Heidenreich, 2006). Offshore personnel tend to

be continually alert for any environmental changes (e.g. in noise, vibration, temperature, or other aspects of the physical environment) which might indicate abnormal operating conditions and possible threats to safety. This heightened vigilance may persist into off-shift hours among anxious personnel, with consequent sleep disturbance acting to impair normal rest and recovery. Hence, the relationship between anxiety and sleep impairment may be accentuated under offshore work conditions relative to leave weeks.

Age also plays an important role in adaptation to shift work, influencing both circadian adjustment to night work and homeostatic aspects of sleep (Härmä et al., 2007). In general, older individuals report greater sleep disturbance (for reviews, see, Cajochen, Munch, Knoblauch, Blatter, & Wirz-Justice, 2006; Ohayon, Carskadon, Guilleminault, & Vitiello, 2004), although some epidemiological findings suggest non-linearity in relations between age and sleep (Grandner, Martin, Patel, Jackson, Gehrman, et al., 2012). More specifically, among shift workers, evidence of curvilinear relations between age and sleep with an upturn at higher ages, has been reported (Marquié, Folkard, Ansiau, & Tucker, 2012; Parkes, 2002). This upturn may be partially attributable to ‘survival’ effects whereby middle-aged personnel who have difficulty adjusting to day/night rotation are more likely to leave shift work; thus, a higher proportion of personnel better able to adapt to circadian disruption remain in the shift work population at older ages.

To date, issues of anxiety and age have received little attention in studies of sleep among offshore shift workers; accordingly, in the light of the findings outlined above, the model tested in the present study included anxiety, and both linear and curvilinear age terms, as predictor variables.

Present Study

The main aim of the present study was to evaluate the extent to which fixed-shift and swing-shift rotation patterns in use on UK North Sea installations are associated with differences in sleep patterns across the three ‘*phases*’ of the offshore work cycle, day shifts (DS), night shifts (NS), and leave weeks (LS), but other independent predictor variables were also examined. The study was based on offshore survey data in which sleep duration and sleep quality were assessed separately for each work

phase. The independent variables analysed included shift rotation and overtime together with individual differences in anxiety, age, and duration of exposure to offshore shift work; in addition, job category and installation type were included to control for task and environmental effects. Based on the literature reviewed in the Introduction, the main hypotheses tested were:

- (i) During offshore work weeks, sleep will be shorter in overall duration and lower in quality than during leave weeks, irrespective of shift roster.
- (ii) DS sleep will be impaired if a day-shift week follows a night-shift week (7N/7D), relative to DS sleep for a day-shift week that precedes a night-shift week (7D/7N).
- (iii) NS sleep will be more favourable for personnel working two consecutive night-shift weeks (14N) than for those working a single week of night shifts (swing-shift rosters).
- (iv) Following an initial night-shift week, DS sleep will be more favourable for personnel working the extended 7N/14D roster than for those working the 7N/7D roster.
- (v) Sleep will be impaired during shore leave that immediately follows a week of offshore night shifts (7D/7N) as compared with a week of day shifts (7N/7D).
- (vi) Overtime, particularly during night shift weeks, will be associated with shorter sleep durations than standard 12 h shifts.
- (vii) Anxiety will be negatively associated with sleep duration and quality; the relationship will be more marked for offshore weeks as compared with leave weeks.
- (viii) Age and shift work exposure will be inversely related to sleep duration and quality; the relationships with age will take a non-linear form.

The same hypotheses were tested for sleep duration and sleep quality as there was insufficient evidence to make separate predictions for the two sleep measures.

Method

Procedure and participants

Data were collected from personnel working on 24 North Sea installations (12 production platforms, 6 drilling rigs, and 6 'Floating Production, Storage and Offloading' vessels, FPSO's).

Researchers visited each installation for 2–4 days, returning subsequently to contact personnel who had been on leave during the initial visit. All personnel on board were invited to participate. Data collection on production platforms and drilling rigs took place some five years prior to data collection on FPSO's, but the same procedure was followed on each occasion. Researchers outlined the study aims, emphasizing that participation was voluntary, that all data would be confidential, and that no information identifying individuals would be disclosed. They also provided written details of the research and distributed survey materials. Completed questionnaires were collected before the researchers left the installation, but a few were returned later by mail. Surveys were identified only by ID numbers, but a confidential list of names and numbers was compiled by the researchers. Participants were offered, and most opted to receive, personal feedback at the end of the study.

Completed questionnaires were received from 1956 personnel (including 10 females). The overall response rate was more than 80%; the range across installations was 67–98%. Analyses were limited to data from male personnel with at least two months' experience of work on their current installation; participants with irregular or varying shift patterns were also excluded, as were 954 personnel who worked only day shifts. Following listwise deletion of missing data ($n=30$) from the remaining sample, the analysis sample consisted of 775 male personnel working shift rotations.

Survey measures

Shift rotation. Three rotation patterns worked during two-week offshore tours were identified: 14N/14D fixed shifts ($n=180$); 7N/7D swing shifts ($n=313$); and 7D/7N swing shifts ($n=181$). In addition, a 7N/14D rotation roster based on three-week tours was included ($n=101$).

Overtime. Four levels of overtime (i.e. hours in excess of 12 h shifts) were identified: none ($n=601$); 1–9 h /week ($n=89$); 10–16 h /week ($n=48$); and > 16 h/week ($n=37$).

Age and shift work exposure. The mean age of participants was 39.9 (SD 9.0) y, range 19 – 64 y. The mean duration of exposure to offshore shift work was 10.8 (SD 6.1) y, range <1 – 36 y.

Anxiety. Anxiety was assessed by the General Health Questionnaire (Goldberg & Hillier, 1979) seven-item anxiety scale (GHQA). Items were scored on a 0–3 scale. The mean score was 4.2 (SD 3.7), range 0 – 21. Coefficient alpha was .83.

Sleep measures. Items assessing sleep duration and sleep quality for day shifts (DS), night shifts (NS), and leave weeks (LS) were included in the questionnaire. Two questions assessed DS sleep duration and quality, respectively: *‘When you are working on day shifts, how many hours do you usually sleep during the off-duty period?’* and *‘How well do you usually sleep during this period?’* A 7-point response scale (0 = ‘Very badly’ to 6 = ‘Very well’) was used for the latter question. The same questions, referenced to night shifts, were used to assess NS sleep. LS sleep was assessed with the questions, *‘When you are on leave, how many hours do you usually sleep at night?’* and *‘How well do you usually sleep when on leave?’*, again using the 7-point response scale for sleep quality.

Control variables

Two variables were included in the analysis to control for environmental and task-related factors.

Type of installation. Personnel from three types of installation took part in the study: production platforms (n=472), drilling rigs (n=185), and FPSO’s (n=118).

Job categories. The job categories were: management (n=31); maintenance (n=204); production (n=259); drilling (n=181); catering (n=9); administration (n=26); construction/deck/ marine (n=65).

Statistical analysis

ANCOVA model. Separate analyses were carried out for sleep duration and sleep quality. In each case, work phase (DS, NS, and LS) was treated as the repeated-measures factor in a mixed-model ANCOVA, carried out using the GLM Repeated Measures procedure in SPSS-19. The independent variables were shift roster and overtime (treated as between-group factors), and anxiety, age, and shift work exposure (treated as continuous variables); age was converted to standardized scores to facilitate testing curvilinear (quadratic) terms. Job category and type of installation were included as control variables. A simultaneous analysis was used, each independent variable being adjusted for all others in the model. To correct for violations of sphericity, Greenhouse-Geisser adjustments were applied. To examine the significant interactions between the repeated-measures factor, *phase*, and one or more ‘between-subjects’ factors, univariate ANOVA’s were carried out. In comparing shift rotations, fixed-shift rotation was treated as the reference condition, allowing use of regression coefficients (B values) to compare this roster with each of the swing-shift rosters. For direct pair-wise comparisons within the swing-shift rotations, adjusted scores were used and Bonferroni corrections were applied.

Calculation of intraclass correlations. The ANCOVA analysis outlined above did not take into account the clustered structure of the observations due to the fact that, for analysis purposes, data from a total of 24 individual installations were grouped into three installation types (see Method section). Within this design, personnel on a particular installation would be expected to show greater similarity of responses to others on that installation than to personnel on different installations, resulting in non-independent observations. Consequently, the assumption that each observation was independent of all others (the basis of normal regression methods) was not met, potentially leading to inflated alpha levels.

To estimate the possible impact of clustering on the present analysis, the intraclass correlation (ICC) was calculated for each dependent measure. Using the method described by Cohen, Cohen, West and Aiken (2003), ICC values were estimated from a series of fixed-effects, non-repeated, one-factor ANOVA's (one for each dependent measure), in which 'installation' was the grouping factor ($n=24$ levels). The following equation, in which the MS values were obtained from the one-factor ANOVA's, and n was the mean cell size (adjusted to take account of unequal groups), was used to derive the ICC values:

$$ICC = \frac{MS_{\text{treatment}} - MS_{\text{error}}}{MS_{\text{treatment}} + (n - 1) MS_{\text{error}}}$$

For the sleep quality measures in the present study, the ICC values were .05, .03, and .02, for DS, NS and LS, respectively. The corresponding values for the sleep duration measures were .08, .01 and .01. Examples given by Cohen et al. (2003) suggest that, for a mean cell size of 25 (comparable to that in the present study), an ICC of 0.01 would increase a nominal alpha level of .05 to .08, and an ICC of 0.05 would increase a nominal alpha level of .05 to .19. These data suggest that interpretation of nominal .05 alpha levels in the present ANCOVA analysis would not be justified. However, it should be noted that, at the 'within-subjects' level of analysis interpreted in the present study, the significant effects all reach alpha levels of .01 or .001; thus, they potentially allow an adequate margin for alpha inflation due to clustering without falling below the conventional .05 level.

Results

Means, deviations and inter-relations among study variables

Descriptive statistics and inter-relationships among the study variables are shown in Table 1. Overall, LS sleep duration and sleep quality were higher than the corresponding DS values, which in turn were higher than the NS values; multiple comparisons showed that all differences among these scores were significant for both sleep measures ($p < .001$ in each case). Age was inversely correlated with DS sleep quality, and with the sleep duration measures. Anxiety was negatively correlated with the sleep quality ratings, but showed less marked correlations with sleep duration. Age and offshore shift work years correlated .67, but anxiety was unrelated to both these measures. Moderate inter-correlations were found among the sleep duration measures and among the sleep quality measures; values ranged from .10 to .43.

Relations between shift rotation and other categorical predictor variables were also examined. Overall, the 7N/7D rotation pattern was the most widely used (40% of participants); 14N/14D fixed-shifts, and 7D/7N rotation each accounted for approximately 23.5% of participants; the three-week 7N/14D roster was the least common (13%). Overtime was relatively unusual; 77.5% of the sample reported no overtime. However, overtime differed significantly across shift rosters ($\chi^2 = 73.2$, $df=9$, $p < .001$); thus, 58% of fixed-shift personnel reported no overtime whereas, in each of the swing-shift groups, the percentage reporting no overtime was more than 80%.

Insert Table 1 about here

Analysis of sleep measures in relation to shift rotation

Table 2 shows the results of the mixed-model ANCOVA for the sleep duration and sleep quality outcome measures. In interpreting the findings, the main focus was on the extent to which the profiles of DS, NS, and LS sleep differed across shift rotations, i.e. on the interaction between phase (within-subjects) and shift roster (between-subjects); in addition, the interactions of phase with overtime, anxiety, age, and offshore shift work exposure were examined. At the between-subjects level, main effects were interpreted only for predictor variables that did not interact with phase.

Insert Table 2 about here

Sleep duration

Phase. As shown in Table 2, phase was highly significant overall in relation to sleep duration.

Pairwise comparisons showed that overall LS sleep duration (7.75h, CI 7.58 - 7.93) was significantly greater than for DS (6.83h, CI 6.66 - 7.00) and NS (6.66h, CI 6.43 - 6.90) ($p < .001$ in each case).

Phase x shift rotation. For sleep duration, the phase x shift rotation interaction was significant ($p < .01$). Figure 1 shows the form of the interaction; mean adjusted DS, NS, and LS sleep hours are plotted for each shift rotation together with the 95% confidence limits.

Insert Figure 1 about here

Day shifts. DS sleep duration for fixed-shift rotation (reference group) was significantly greater than that for 7N/7D rotation ($B = -.38$, $t = -3.86$, $p < .001$), but did not differ significantly from those for the other rotations. Pairwise comparisons across the swing-shift rosters showed that DS sleep duration for the 7N/7D roster (6.57 h) was significantly lower than for the 7N/14D roster (6.98 h) ($p < .01$), but differed only marginally from the 7D/7N roster (6.81 h) ($p = .06$).

Night shifts. NS sleep duration for the fixed-shift roster (6.95 h) was significantly longer than those for 7N/7D rotation (6.59 h) ($B = -.35$, $t = -2.59$, $p = .01$), 7N/14D rotation (6.53 h) ($B = -.41$, $t = -2.28$, $p < .025$) and 7D/7N rotation (6.58 h) ($B = -.37$, $t = -2.34$, $p < .025$), but differences in NS sleep duration across the three swing-shift conditions were all non-significant.

Leave weeks. The four rotation patterns did not differ significantly in LS sleep duration but, consistent with the main effect of phase, sleep duration was higher during leave weeks than during offshore weeks irrespective of shift rotation pattern.

Overtime. As shown in Table 2, the main effect of overtime on sleep duration did not reach the .05 level ($p < .06$). However, as predicted, overtime was significantly negatively related to NS sleep duration ($F = 3.15$, $df = 3$, $p = .025$), but not to DS or LS sleep. The highest level of overtime (> 16 h/week) was associated with significantly shorter mean NS sleep duration (6.23 h) than the two lowest overtime levels, no overtime ($p < .02$), and 1-9 h/week ($p < .01$), for which mean sleep durations were 6.72 h and 7.04 h respectively.

Phase x covariate interactions

Anxiety. There was a significant interaction between phase and anxiety in predicting sleep duration ($p < .01$). Anxiety was negatively related to sleep duration during offshore weeks but, as shown in Figure 2, the association was stronger for NS sleep ($B = -.040$, $t = -3.06$, $p < .01$) than for DS sleep ($B = -.021$, $t = -2.21$, $p < .05$). LS sleep duration was unrelated to anxiety ($t < 1$).

Insert Figure 2 about here

Age and shift work exposure. Evaluation of age and shift work exposure as simultaneous predictors of sleep duration showed a significant main effect of age ($p < .001$), and a significant interaction between phase and shift work exposure ($p < .01$). Age was negatively related to DS ($p < .05$) and LS sleep duration ($p < .001$) but not to the NS measure. The curvilinear age term was non-significant and was not included in the model. NS (but not DS or LS) sleep duration showed a strong negative association with shift work exposure ($B = -.04$, $t = -3.56$, $p < .001$). Thus, age (controlled for shift work exposure) predicted DS and LS sleep duration, whereas shift work exposure (controlled for age) predicted NS sleep duration.

Control variables. The main effect of installation type was non-significant but there was a significant interaction with phase, attributable to differences across installation types in DS sleep duration, but not in the NS or LS measures. Job category was non-significant at both analysis levels.

Sleep quality

Phase. As shown in Table 2, phase was a highly significant overall predictor of sleep quality ($p < .001$); pairwise comparisons showed that LS sleep quality (4.65, CI 4.47 - 4.84) was significantly higher than DS (3.68, CI 3.47 - 3.90) and NS (3.20, CI 2.95 - 3.45) sleep quality. Both comparisons were highly significant ($p < .001$).

Phase x shift rotation. Sleep quality was predicted by a significant interaction of phase with shift rotation ($p < .01$). Details of the findings for DS, NS and LS sleep quality are outlined below, and the adjusted sleep quality scores for each shift rotation, and the 95% CL limits, are shown in Figure 3.

Insert Figure 3 about here

Day shifts. Each of the swing-shift rotations showed lower DS sleep quality than fixed-shift rotation. The most marked difference was for fixed shifts compared with 7N/7D ($B = -.70$, $t = -5.70$, $p < .001$), but both 7D/7N ($B = -.43$, $t = -3.02$, $p < .01$) and 7N/14D ($B = -.44$, $t = -2.70$, $p < .01$) also showed lower DS sleep quality than the fixed-shift reference group. Pairwise comparisons of sleep quality across the swing-shift rosters showed no significant differences.

Night shifts. NS sleep quality was marginally higher for the fixed-shift rotation than for the other three rosters but overall differences across shift rotations were non-significant.

Leave weeks. LS sleep quality was higher for the fixed-shift roster as compared with the two-week swing-shift rosters; the difference was significant for 7N/7D rotation ($B = -.23$, $t = -2.19$, $p < .05$), but only marginal for 7D/7N rotation ($B = -.23$, $t = -1.93$, $p < .06$). The 7N/14D three-week rotation did not differ significantly in LS sleep quality from fixed-shift rotation.

Overtime. Overtime did not interact significantly with phase in predicting sleep quality, nor did it show a significant main effect, although there was a weak trend by which higher levels of overtime were associated with poorer sleep quality ($p < .12$).

Anxiety. Anxiety was negatively related to DS, NS and LS sleep quality; the significant phase x anxiety interaction reflected the steeper gradient of the DS and NS regression lines relative to LS. The relationships between anxiety and sleep quality were of similar magnitude for DS ($B = -.09$, $t = -7.54$, $p < .001$) and NS sleep ($B = -.11$, $t = -7.53$, $p < .001$). For LS sleep quality the relationship was also significant but less marked ($B = -.04$, $t = -3.96$, $p < .001$).

Age and duration of offshore shift work exposure. The simultaneous analysis model included linear and curvilinear age terms, together with shift work exposure years. The curvilinear interaction between phase and age was highly significant. This interaction was due specifically to the relationship between age and NS sleep quality ($B = .16$, $t = 3.29$, $p < .001$). As shown in Figure 4, NS sleep quality decreased from the youngest age (20 y, z score -2.0) to ages 38-42 y (z scores -0.1 to 0.4), and then gradually increased again for ages >42 y. In contrast, the relationship of age to DS sleep quality showed a weak negative trend ($p < .10$), with no curvilinear component ($t < 1$), while LS sleep quality was unrelated to age. The linear interaction between shift work exposure and phase was also

significant; exposure years negatively predicted NS ($B = -.032$, $t = -2.85$, $p < .01$), but not DS or LS, sleep quality. In summary, the curvilinear age term, and the duration of shift work exposure (each adjusted for the other) were significantly related to NS sleep quality, but not to the DS or LS measures.

Insert Figure 4 about here

Control variables. Installation type was non-significant as a main effect but showed a significant interaction with phase, due largely to lower DS sleep quality on FPSO vessels relative to other installation types. Job category was non-significant at both levels of analysis.

Conclusions

The present study sought to extend existing survey research into the sleep patterns of offshore workers by testing a series of hypotheses about sleep duration and quality in relation to shift rotation rosters, overtime levels, and individual differences. Particular features of the study design included: separate sleep measures for each of three phases of the offshore work cycle (day shifts, nights shifts and leave weeks); evaluation of a three-week roster in addition to two-week rosters; assessment of overtime hours (i.e. shift durations >12 h); and inclusion of individual differences in age, shift work exposure years, and anxiety. This Discussion section reviews the study findings in relation to the initial hypotheses; more general implications of the research are also considered, and methodological limitations of the work are noted.

Hypothesis (i) was supported for both sleep measures. In particular, as in earlier studies (Parkes, 1994; Saksvik et al., 2011a), LS sleep duration was, on average, ~ 1 h longer per day than DS sleep, and ~ 1.2 h longer per day than NS sleep. Several environmental factors contribute to sleep impairment offshore; in particular, noise is a major cause of sleep disturbance (Mearns & Hope, 2005), but other potential causes include shared cabins (Lauridsen et al., 1991; Mearns & Hope, 2005), severe wind and sea conditions (Haward et al., 2009), and early (06.00 h) shift start times (Thorne, Hampton, Morgan, Skene, & Arendt, 2008). The smallest differences in sleep duration

between offshore weeks and leave weeks occurred when leave followed 14 consecutive day shifts (i.e. 14D and 7N/14D rosters), and thus no circadian adaptation at home was required.

Hypothesis (ii) was also supported for both sleep measures. Sleep duration and quality were lower for the 7N/7D roster than for the 7D/7N roster; this finding is consistent with physiological evidence suggesting that, following a week of offshore night work, little re-adaptation is achieved during the subsequent day-shift week (Gibbs et al., 2007; Waage et al., 2012). The 7N/7D roster also showed impaired sleep relative to the 14D fixed-shift roster.

Hypothesis (iii) was supported only for sleep duration; NS sleep duration for the 14N fixed-shift roster was significantly longer than for swing-shift rosters in which nights were worked for only one week. Differences in NS sleep duration between the 14N rotation and the swing shift rosters were 20-25 minutes per day; however, irrespective of roster, the 95% confidence intervals for NS sleep duration did not fall below 6 h per night, identified as the minimum level below which marked cognitive deficits are observed (Van Dongen, Maislin, Mullington, & Dinges, 2003).

Hypothesis (iv). Consistent with the longer period available for circadian re-adaptation when two weeks of day shifts follow an initial night-shift week, DS sleep for the 7N/14D roster was more favourable than for the 7N/7D roster. However, neither the NS nor the LS measures showed significant differences between the 7N/14D and the 7N/7D rosters. Thus, the extended three-week swing-shift roster showed little overall advantage, and the findings do not suggest that wider use of this roster would have substantial benefits. Although longer tours would reduce the frequency of helicopter flights and overall travel times, three-week tours increase the risk of cumulative fatigue, and are disliked by many offshore families (Parkes & Clark, 1997).

Hypothesis (v) was not supported. No significant differences were found between the 7D/7N and 7N/7D rosters for the LS sleep measures, even though working night-shifts during the second week offshore might be expected to impair sleep during the first week of leave. It is possible that incomplete adaptation to night work when working the 7D/7N roster facilitates re-adaptation to a normal diurnal cycle during subsequent leave weeks, but conflicting results have been reported for objective and subjective sleep measures (Saksvik et al., 2011a; Waage et al., 2012).

Hypothesis (vi) was partially supported. NS sleep duration was significantly negatively related to overtime; the mean adjusted difference in NS sleep duration between the highest overtime level (≥ 16 h/week) and no overtime was about half an hour (.53 h). It is possible that overtime that extends night shifts by 1-2 hours results in greater exposure to morning light, thus impeding adaptation to night work, and impairing daytime sleep. This interpretation accords with evidence of longer sleep duration among offshore personnel working 12 h night shifts ending at 06.00 h as compared with 07.00 h (Thorne et al., 2008). However, although predicted, and consistent with other evidence (e.g. Son et al., 2008), the present finding of shorter NS sleep associated with a high level of overtime should be viewed cautiously as the proportion of personnel reporting overtime was relatively small.

Hypothesis (vii), which implied that sleep would be predicted by the interaction between phase and anxiety was supported for both sleep duration and quality. In each case, the negative relationship between anxiety and sleep was stronger for offshore weeks (DS and NS) than for leave weeks (LS). As outlined in the Introduction, anxiety is associated with impaired sleep (e.g. Strine & Chapman, 2005), and with a tendency to constantly monitor the environment for signs of threat (Voss, Kolling, & Heidenreich, 2006). The present findings suggest that, among anxious offshore personnel, heightened vigilance for environmental safety risks may continue into off-shift hours, and consequently impair normal rest and recovery. Whilst the present study did not allow causal direction to be determined, it is possible that elevated levels of anxiety and distress may co-exist with sleep impairment offshore in a bi-directional relationship, as has been found in onshore studies (Jansson-Fröjmark & Lindblom, 2008; Sivertsen, Salo, Mykletun, Hysing, Pallesen et al., 2012), and that exposure to physical and psychosocial stressors in the offshore environment may be implicated in this association.

Hypothesis (viii) was partially supported. For sleep duration, consistent with other findings for offshore shift workers (Waage et al., 2010), there was a significant overall effect of age, largely due to the negative relationship between LS sleep duration and age. However, the phase x age interaction was not significant when controlled for shift-work exposure. In contrast, for sleep quality, there was a highly significant quadratic interaction between phase and age; only NS sleep quality showed a

curvilinear relationship with age. As predicted, minimum values for NS sleep quality occurred in the middle age range while, at the highest ages (>59 y), NS and DS sleep quality levels were similar.

These findings are consistent with ‘selection out’, whereby older workers (ages of 45+ years) who have difficulty adapting to night work move to permanent day work or leave the industry, thus producing an apparent improvement in the night-shift sleep of those who remain in shift work (Knutsson & Åkerstedt, 1992; Marquie, Foret, & Queinnec, 1999; Tucker et al., 2011). However, the present analysis suggests that the apparent improvement in sleep among older shift workers applies only to NS sleep quality. No specific prediction was made about the role of shift work exposure years but, over and above age, this variable was negatively related to NS (but not DS or LS) sleep duration and sleep quality measures, suggesting a possible cumulative effect on NS sleep of long duration exposure to shift work.

Implications for the offshore industry

The findings of the present study not only contribute to existing offshore research but also have implications for the North Sea oil/gas industry. Whilst the cross-sectional design of the present study does not allow causal interpretation, the analyses suggest that shift rotation rosters, overtime, anxiety, age and exposure to offshore shift work contribute independently to the duration and quality of sleep reported by offshore personnel. However, the patterns of findings differed across the profile of DS, NS and LS measures; in general, NS sleep was most strongly related to the independent variables.

Shift rotation offshore. In highlighting sleep impairments associated with swing-shift rosters (particularly 7N/7D) relative to fixed-shift rosters, the present results suggest that findings from small-scale physiological studies apply to offshore personnel more generally, and lead to the view that fixed-shift rotation rosters have significant benefits in terms of sleep, and hence alertness and performance during work hours. However, from a management viewpoint, the advantages of fixed-shift rotation in reducing circadian disruption and associated safety risks have to be balanced against wider issues such as arranging shift handovers, crew changes, work/ leave schedules, and the logistics of helicopter operations. Moreover, most offshore workers strongly dislike having to re-adapt to a normal diurnal cycle during leave weeks. Thus, although 14N night-shift sequences occur only once

every 8-10 weeks for fixed-shift schedules on UK installations, these rosters may detract from the recruitment and retention of key operating personnel. Managing the elevated risks associated with swing shifts is considered by many industry managers to be a better solution than imposing unwelcome roster changes (Parkes, 2010).

Consequently, the 7N/7D rotation pattern remains in common use, in spite of the disruption to alertness and performance resulting from two 12 h circadian changes during a two-week offshore tour. Although these adverse effects are widely recognized in the industry, research indicating that frequent circadian disruption is also associated with long-term health impairment is less well known. Swing-shift rosters impose 12 h circadian changes twice as frequently as fixed-shift rosters. Evidence suggests that day/night shift changes, disruption of circadian rhythms, and consequent internal physiological desynchrony, may be implicated in the link between shift work and chronic ill-health, including cardiovascular disease and metabolic disturbances (e.g. Figueiro & White, 2013; Puttonen, Härmä, & Hublin, 2010; Scheer, Hilton, Mantzoros, & Shea, 2009). The possibility that more frequent circadian changes, inherent in swing-shift rosters, could represent a risk factor for long-term health impairment adds further weight to arguments in favour of fixed-shift rotation.

Overtime. Overtime work represents an additional demand over and above the long work hours, shift changes, and environmental stressors experienced offshore; UK guidelines for the offshore industry recommend that total work time per shift should not exceed 14 h, and that a risk assessment should be carried out before overtime is permitted (Health and Safety Executive, 2009). Overall, fewer than 25% of the present sample of shift workers reported overtime, as day workers undertake the majority of overtime offshore. Specific findings linking high levels of overtime to shorter NS sleep in the present study can only be regarded as tentative, but the issue of overtime work offshore would merit greater attention than it has yet received; in particular, research examining the duration and consequences of overtime worked offshore, its association with job and individual characteristics, and its impact on the sleep, health and safety of personnel, would be a valuable addition to the literature.

Individual Differences. The present study demonstrated a complex pattern of findings for the relationships of anxiety, age (both linear and curvilinear terms) and shift work exposure with the

sleep quality and duration measures. In general, the individual difference variables were most strongly predictive of NS sleep. Thus, NS sleep appeared to be particularly vulnerable to long exposure to offshore shift work and to high anxiety. However, the findings also showed an apparent improvement in NS sleep quality among older personnel (after control for shift work exposure), most probably due to ‘survivors’ who are better able to adapt to day/night rotation than those who leave shift work in middle age (Marquié et al., 2012; Tucker et al., 2011). For the offshore industry, this interpretation implies that experienced shift workers may be lost from the industry at an age when they would normally be in senior positions (e.g. production supervisors) and that sleep problems during night work may be at least partly responsible. At a time when skilled offshore personnel are much in demand, and are encouraged to remain in offshore employment longer than has previously been customary, the present findings suggest that reducing night-shift sleep problems among older workers should be a particular focus of attention.

Methodological issues

The main limitation of the present study was the use of cross-sectional data, the familiar weaknesses of which (specifically, ambiguity about the nature and direction of causal effects) constrain interpretation of the findings. In particular, the sleep measures were self-reported, rather than derived from objective (actigraphic) recordings; however, evidence suggests consistent agreement between objective and subjective sleep data (e.g. Saksvik et al., 2011a). In addition, the practical constraints of large-sample offshore survey methods did not allow adaptation to 12 h shift changes to be tracked day-by-day, as is possible in small-scale field studies. Instead, the present measures provided subjective overall assessments of sleep for the three phases of the work cycle.

It is also necessary to consider whether the sleep data might have been biased by the particular stage of the tour at which individuals completed survey. Information about time of completion was not recorded, but the researchers distributed survey questionnaires to all participants on board irrespective of whether they were working day or night shifts at the time, and how many days they had been offshore on their current tour. Thus, any biases associated with time of completion of the survey would effectively have been balanced out across the sample as a whole. Other methodological points to note were that, to avoid an over-long questionnaire, single items were used to assess sleep

duration and quality, and no measure of chronotype (which might have thrown further light on the sleep patterns observed for different rosters) was included. In spite of these methodological limitations, the agreement between the findings for the different rosters examined in the present study and those from small-scale intensive field studies lends support to the validity of the present data.

Several aspects of the data analysis also merit comment. In particular, obtaining separate sleep measures for the three phases of the offshore work cycle allowed use of a repeated-measures analysis model in which phase was the within-subjects factor. Thus, the analysis focused on patterns of sleep over DS, NS and LS in relation to shift rosters and the other independent variables (i.e. on interactions of phase with other predictors, rather than on main effects). This approach partially mitigates the problems of individual response tendencies and ‘third factor’ effects that may distort the findings of analyses using single outcome variables. In addition, several of the independent variables used were factual in nature (e.g. shift roster, age, years of offshore shift work), and therefore less vulnerable to self-report biases. It is of course possible that subjective perceptions of the work environment may act as mediators of relations between these objective characteristics and sleep outcomes; this issue, although not addressed in the present work, deserves further study.

In relation to the analysis model, it is important to be aware that the present data were collected in two stages (in 1996-7 for production platforms and drilling rigs, and in 2002 for FPSO’s). Thus, installation type was partially confounded with systematic changes, if any, occurring across the 5-6 year time interval. Inclusion of installation type in the analysis served to control for the joint effects of differences across different types of installations and possible changes over time, although these effects could not be separated. Few significant results for this variable were observed; they were independent of other findings, and were not interpreted. In this context, it should also be noted that several different installations were included in each installation type, thus producing a clustered data structure in which observations within a particular installation were not independent (see Statistical Analysis section). In practice, the values of the intraclass correlations calculated to address this issue were relatively small, while the alpha values for the substantive effects interpreted reached the levels of $<.01$ or $<.001$; hence, as far as could be determined, it did not appear that inflation of alpha values due to clustered data was a serious threat to the adequacy of the present analysis. Nonetheless, the

increasing sophistication of multilevel statistical methods could offer an alternative and potentially more rigorous approach to the analysis of complex repeated-measures designs.

Relevance of the study to current offshore work conditions. As the data were collected some years ago, a further significant issue is whether the present results remain applicable to offshore shift work as currently scheduled. In practice, the rosters studied are still in use, 12 h shifts and overtime hours are still worked, shared cabins without exposure to natural light are still the norm, and the average age of the workforce has not changed substantially. This relatively stable environment suggests that the findings reported here remain relevant to current offshore work conditions. Moreover, it is clear that the scheduling of shift rotation on North Sea installations is still a major concern, not only in recent research publications (e.g. Saksvik et al., 2011a; Waage et al., 2012; Waage, Pallesen, Moen, & Bjorvatn, 2013), but also among regulatory agencies, oil/gas industry managers, and the offshore workforce (Parkes, 2010).

The extent to which the present sample can be regarded as representative of the UK North Sea workforce should also be considered. The high response rate (>80% overall), together with collection of data from different types of installations, operated by a different companies (ranging from multi-national operators to much smaller organizations) located in the main areas of North Sea oil/gas activity, provides support for the view that the sample was generally representative of the UK offshore workforce when the data were collected. In addition, the demographic characteristics of the sample (e.g. age, years of offshore shift work, proportions in particular job categories) were consistent with those of recent large-scale surveys of North Sea personnel (Bjerkan, 2010; Hope et al. 2010; Høivik, Baste et al. 2007). Moreover, there was no evidence to suggest that the findings were biased by the omission of a small number of participants (n=30) from the analysis sample (n=775) because of missing data. Thus, albeit cautiously, it can reasonably be concluded that the present findings would be generally applicable to the wider North Sea community.

Further work. Finally, it should be emphasised that, although progress has been made in understanding the problems of adaptation to offshore shift rotation, and the effects of North Sea work on health and safety more generally, important methodological gaps in the research literature remain. In particular, there are very few prospective studies of the work environment and general well-being

of offshore personnel (for one example, see Nielsen, Tvedt, & Matthiesen, 2012), and none that examine the long-term effects of different shift rotations, in spite of the possible impact of frequent circadian changes on long-term health. One problem in attempting such research is the global employment mobility of offshore personnel which impacts adversely on follow-up rates. Nonetheless, a large-scale prospective study of North Sea personnel based on survey methods, but ideally also including objective exposure data, and independent medical and accident/injury records, would be a valuable addition to the existing literature on health and safety of offshore personnel.

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Correspondence concerning this article should be addressed to the author at the Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford, OX1 3UD, UK. E-mail: kathy.parkes@psy.ox.ac.uk.

Table 1

Means, Standard Deviations and Inter-Correlations among the Study Variables

Measure		Mean	SD	Shift work years	Anxiety	Sleep duration			Sleep quality		
						DS	NS	LS	DS	NS	LS
Age (y)		38.8	8.9	.67**	.02	-.19**	-.14**	-.24**	-.14**	-.05	-.05
Shift work years		10.8	6.1	----	.03	-.16**	-.19**	-.20**	-.10**	-.12**	-.06
Anxiety		4.2	3.7		---	-.08*	-.12**	.00	-.26**	-.28**	-.15**
Sleep duration	DS	6.9	1.0			---	.37**	.34**	.44**	.06	.18**
	NS	6.6	1.4				---	.19**	.15**	.50**	.02
	LS	7.9	1.0					---	.10**	-.01	.25**
Sleep quality	DS	3.8	1.3						---	.43**	.37**
	NS	3.1	1.5							---	.15**
	LS	4.9	1.1								---

DS = Day shifts, NS = Night shifts LS = Leave weeks

N=775, ** p <.01

Table 2

Mixed-Model Analyses of Variance Predicting Sleep Duration and Sleep Quality over Three Shift Phases (Day Shifts, Night Shifts, and Leave Weeks)

	Sleep duration				Sleep quality			
	<i>F</i>	<i>df</i>	<i>p</i> [†]	Partial η^2	<i>F</i>	<i>df</i>	<i>p</i> [†]	Partial η^2
<i>Within subjects</i>								
Phase (P)	12.73	2, 1514	<.001	.017	13.87	2,1512	<.001	.018
P x Shift rotation	3.15	6, 1514	<.01	.012	2.98	6,1512	<.01	.012
P x Overtime	1.33	6, 1514	<i>ns</i>	.005	1.58	6,1512	<i>ns</i>	.006
P x Anxiety	5.19	2,1514	<.01	.007	10.39	2,1512	<.001	.014
P x Shift work years	5.25	2,1514	<.01	.007	5.11	2,1512	<.01	.007
P x Age	1.53	2,1514	<i>ns</i>	.002	2.16	2,1512	<i>ns</i>	.003
P x Age ²	---	---	---	---	5.00	2,1512	<.01	.007
P x Installation type	4.05	4, 1514	< .01	.011	7.94	4,1512	<.001	.021
P x Job category	1.36	12,1514	<i>ns</i>	.011	<1	12,1512	<i>ns</i>	.004
<i>Between subjects</i>								
Shift rotation	3.45	3,757	<.02	.013	5.94	3,756	.001	.023
Overtime	2.50	3,757	[<.06]	.010	2.00	3,756	<i>ns</i>	.008
Anxiety	6.28	1,757	<.02	.008	80.73	1,756	<.001	.096
Shift work years	8.07	1,757	<.01	.011	2.35	1,756	<i>ns</i>	.003
Age	11.57	1,757	.001	.015	<1	1,756	<i>ns</i>	.000
Age ²	---	---	---	---	4.82	1,756	<.05	.006
Installation type	2.61	2, 757	<i>ns</i>	.007	2.77	2,756	<i>ns</i>	.007
Job category	1.29	6,757	<i>ns</i>	.010	1.12	6,756	<i>ns</i>	.009

[†] Significance levels are shown with Greenhouse-Geisser adjustment

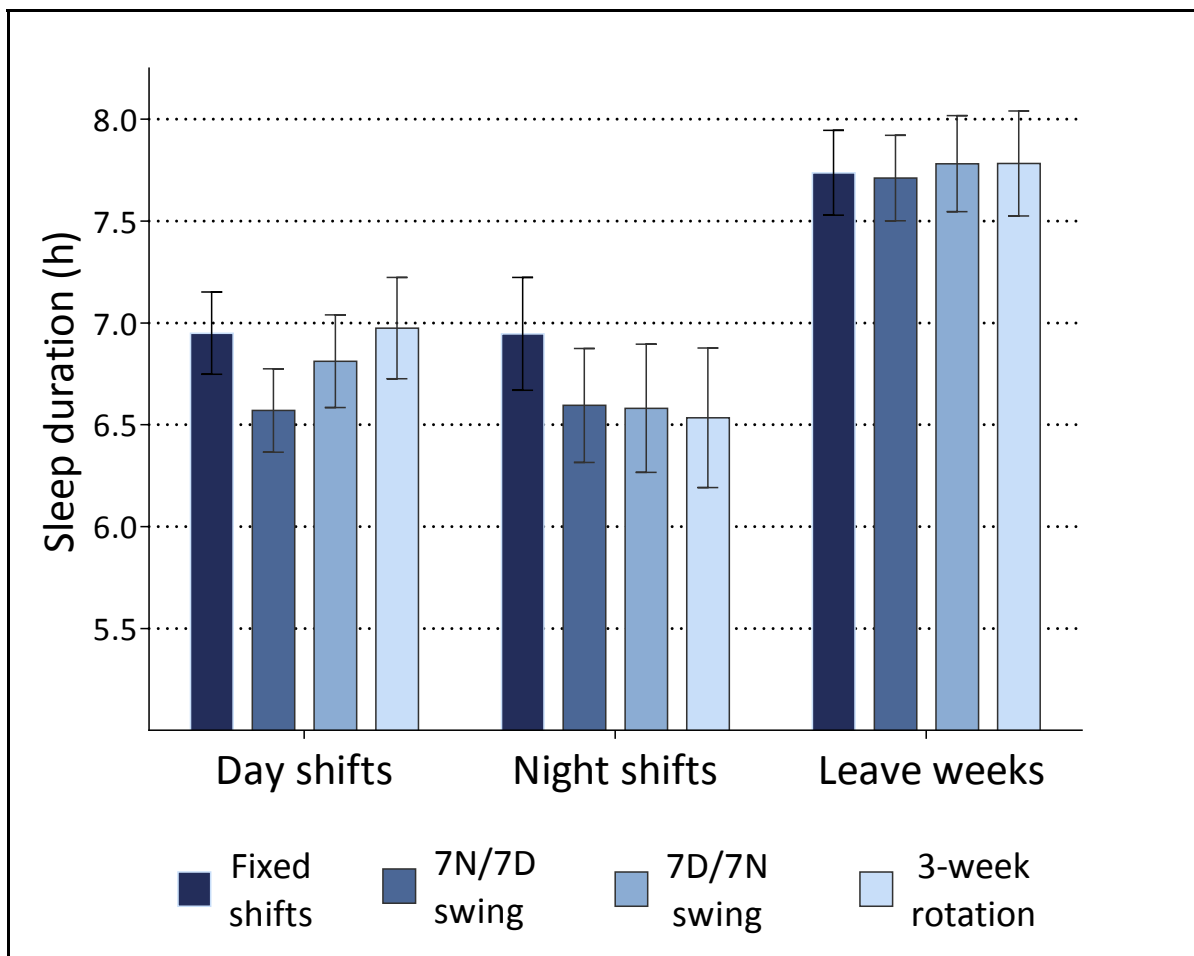


Figure 1. *Sleep Duration for Day Shifts, Night Shifts, and Leave Weeks in Relation to Shift Rotation Rosters*

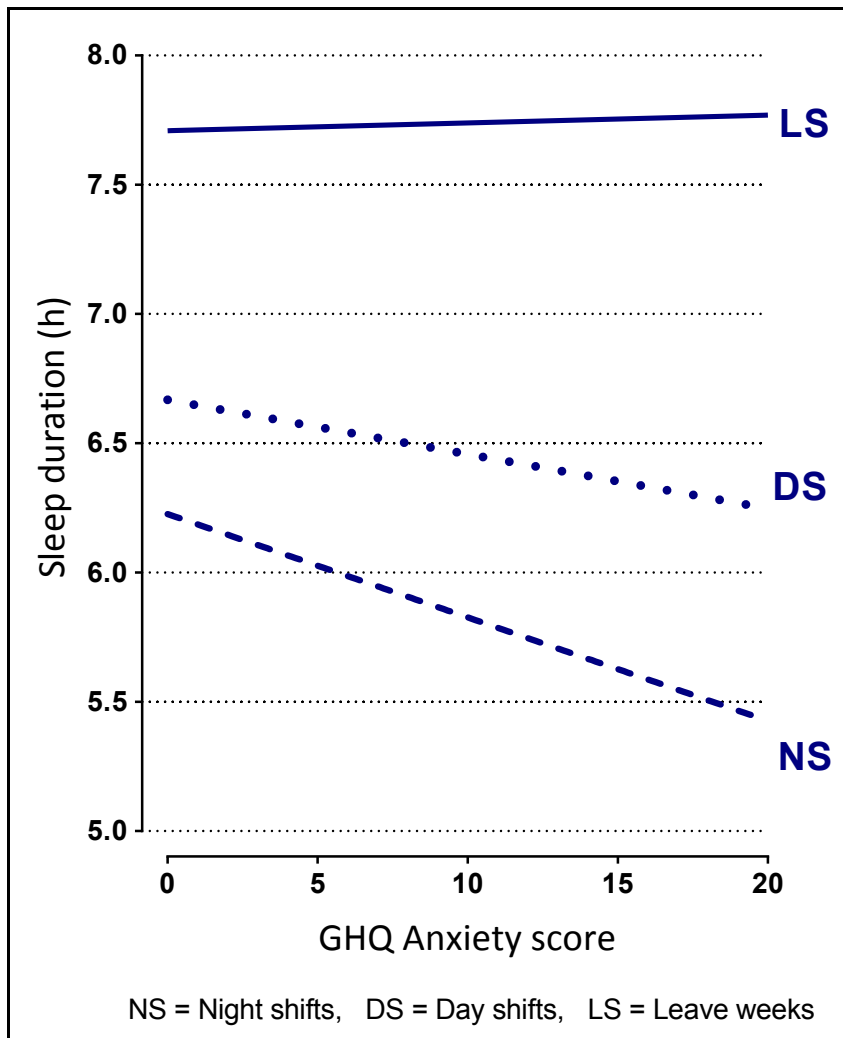


Figure 2. *The Relationship between Anxiety and Sleep Duration for Day Shifts, Night Shifts, and Leave Weeks*

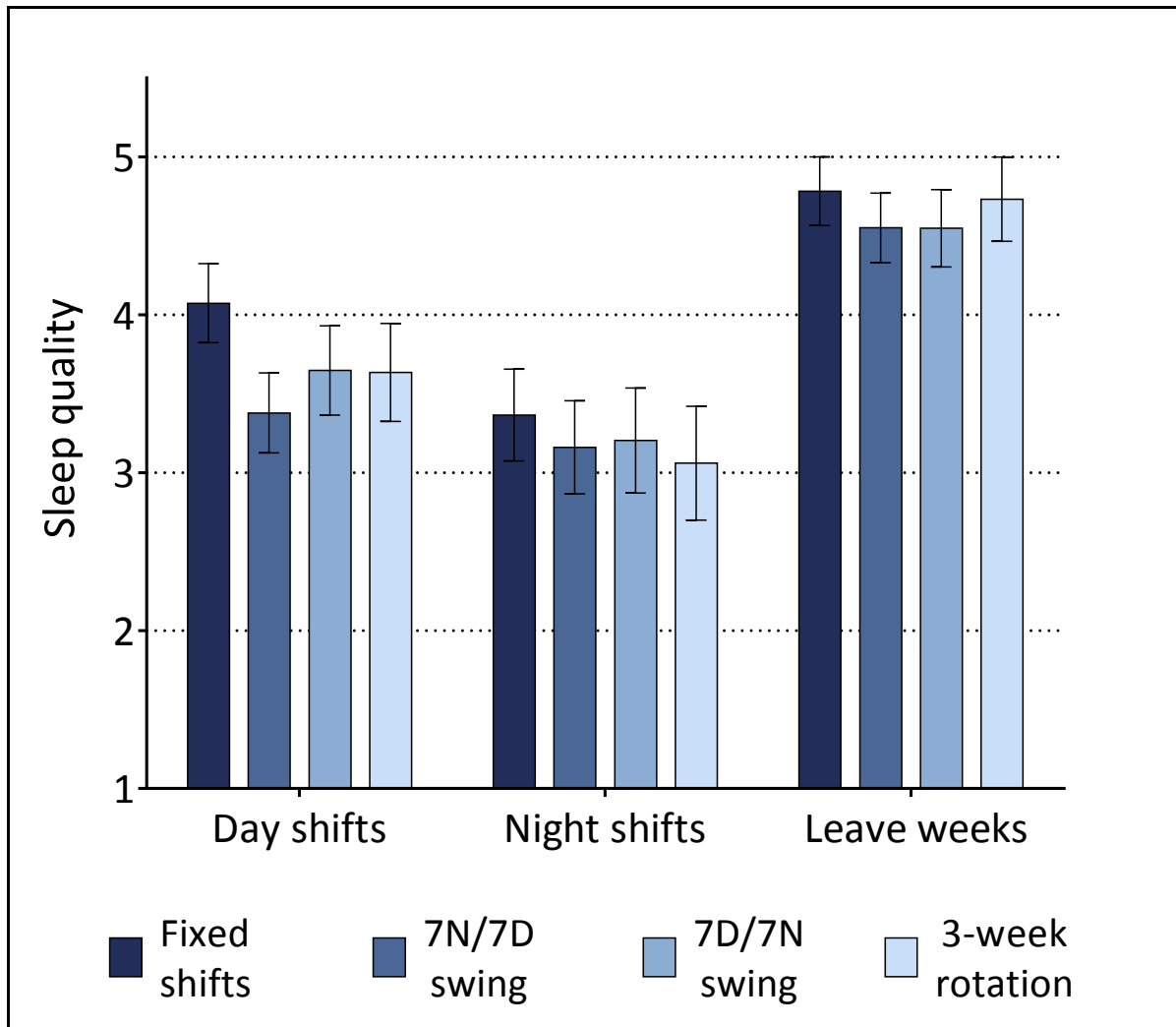


Figure 3. *Sleep Quality for Day Shifts, Night Shifts, and Leave Weeks in Relation to Shift Rotation Rosters*

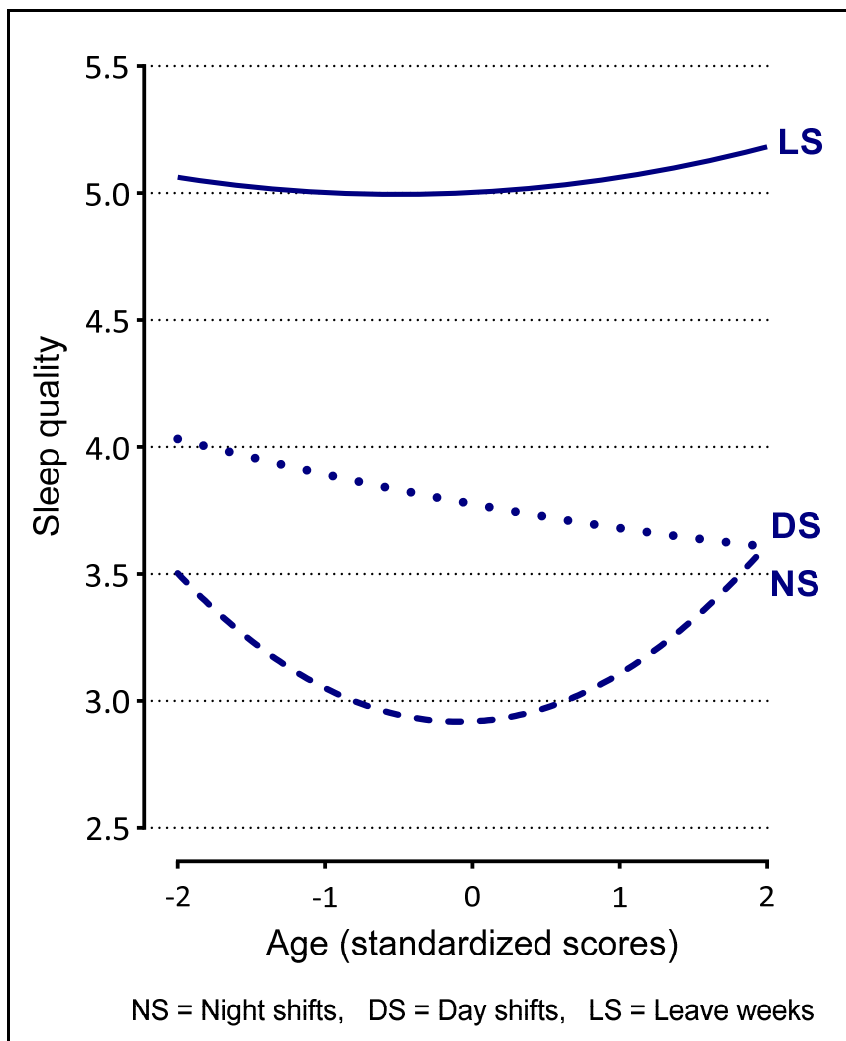


Figure 4. *The Relationship between Age and Sleep Quality for Day Shifts, Night Shifts, and Leave Weeks*