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This paper reviews the implications of limited wake shift work schedules, such as the 6hr-on/6hr-off and 4hr-on/8hr-off watchkeeping schedules employed by mariners and the 8hr-on/8hr-off schedules of long-haul train drivers. These schedules are reviewed within a chronobiological framework and recommendations are made to optimize sleep and performance.

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A systematic review of the sleep, sleepiness, and performance implications of limited wake shift work schedules

by Michelle A Short, PhD,^{1,2,3} Alexandra Agostini, BPsychSci(Hons),¹ Kurt Lushington, PhD,¹ Jillian Dorrian, PhD¹

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Objectives The aim of this review was to identify which limited wake shift work schedules (LWSW) best promote sleep, alertness, and performance. LWSW are fixed work/rest cycles where the time-at-work does is ≤ 8 hours and there is >1 rest period per day, on average, for ≥ 2 consecutive days. These schedules are commonly used in safety-critical industries such as transport and maritime industries.

Methods Literature was sourced using PubMed, Embase, PsycInfo, Scopus, and Google Scholar databases. We identified 20 independent studies (plus a further 2 overlapping studies), including 5 laboratory and 17 field-based studies focused on maritime watch keepers, ship bridge officers, and long-haul train drivers. The measurement of outcome measures was varied, incorporating subjective and objective measures of sleep: sleep diaries (N=5), actigraphy (N=4), and polysomnography, (N=3); sleepiness: Karolinska Sleepiness Scale (N=5), visual analog scale (VAS) alertness (N=2) and author-derived measures (N=2); and performance: Psychomotor Vigilance Test (PVT) (N=5), Reaction Time or Vigilance tasks (N=4), Vector and Letter Cancellation Test (N=1), and subjective performance (N=2).

Results Of the three primary rosters examined (6 hours-on/6 hours-off, 8 hours-on/8 hours-off and 4 hours-on/8 hours-off), the 4 hours-on/8 hours-off roster was associated with better sleep and lower levels of sleepiness. Individuals working 4 hours-on/8 hours-off rosters averaged 1 hour more sleep per night than those working 6 hours-on/6 hours-off and 1.3 hours more sleep than those working 8 hours-on/8 hours-off ($P < 0.01$). More broadly, findings indicate that LWSW schedules were associated with better sleep and lower sleepiness in the case of (i) shorter time-at-work, (ii) more frequent rest breaks, (iii) shifts that start and end at the same clock time every 24 hours, and (iv) work shifts commencing in the daytime (as opposed to night). The findings for performance remain incomplete due to the small number of studies containing a performance measure and the heterogeneity of performance measures within those that did.

Conclusion The literature supports the utility of LWSW in industries where individuals sleep at or near the workplace as they facilitate at least some sleep during the biological night and minimize deficits associated with time-on-shift with shorter shifts. Overall, the 4 hour-on/8 hour-off roster best promoted sleep and minimized sleepiness compared to other LWSW schedules. Nevertheless, and considering the safety-critical nature of industries which employ LWSW, the limited literature needs to be greatly expanded with specific focus on the consequences for performance and comparison to mainstream rosters.

Key terms continuous operation; performance; split shift; split sleep; sustained operation.

Many industries require continuous, around-the-clock operations, for example, defense, emergency services, health, manufacturing, mining and transport, as well as more rarefied occupations such as space operations (1–6). These industries face a challenge in how to prevent the decrements in safety, alertness, and per-

formance that arise from spending a prolonged time at work and working nights. One strategy has been to redistribute time-at-work into smaller aliquots that are spaced equally across the 24-hour period. Commonly employed short cycling work/rest routines or limited wake shift work (LWSW) schedules include 6 hours-

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on/6 hours-off, 4 hours-on/8 hours-off and 8 hours-on/8 hours-off schedules. These types of shift schedules minimize the number of consecutive hours at work, promote rest opportunities between work bouts, and allow for at least some opportunity for sleep during the night for all workers (7–11). Given the safety-critical nature of many of the industries that employ LSW and the emerging research activity in this field, a review of the current literature is timely. In particular, there is a need to identify which LSW schedules best promote sleep, minimize sleepiness, and facilitate performance.

There is a general consensus that the impact of shiftwork on sleep, sleepiness, and performance is mediated by three factors: (i) time-of-day or circadian effects; (ii) the length of time-at-work (and conversely the opportunity for sleep); and (iii) the consistency of start and finish times (8, 12, 13). Taking each of these factors in turn, the impact of the circadian system is such that the maximum drive for sleep, the highest levels of sleepiness, and lowest performance tend to occur during the early hours of the morning (12, 14) also known as the circadian nadir (15). By contrast, the likelihood of sleep and, likewise, sleepiness are at their lowest in the early evening period also known as the “forbidden sleep zone” or the “wake maintenance zone” (WMZ) (16). Sleep, sleepiness, and performance are also strongly influenced by the length of time spent awake and, in turn, the opportunity for sleep, which are primarily dictated by shift length and the timing of shift cycles (8). Generally, shift schedules that possess a high work-to-rest ratio (ie, where workers spend a longer time at work and have shorter times between shift) are associated with poorer circadian alignment and shorter sleep (17). Likewise shift schedules where start and finish times are inconsistent from one 24-hour cycle to the next and, as a consequence, the timing work/rest bouts (18, 19).

While the factors identified above are relatively well explored in more commonly worked shiftwork schedules (eg, 8 hours-on/16 hours-off), they have received less attention in LSW. Nevertheless, it is expected that the same trends will be evident. Specifically, it is hypothesized that LSW schedules will be associated with shorter sleep, greater sleepiness and poorer performance where (i) more of the work time falls across the circadian nadir, (ii) more of the sleep opportunity falls during the WMZ, (iii) the work-to-rest ratio is high, and (iv) the consistency in the timing of work/rest bouts from one 24-hour cycle to the next is low (20, 21). The aim of this review is to test these hypotheses and determine which LSW schedules best promote sleep, alertness, and performance. Given the differences across studies in schedules and methodology, where possible, these hypotheses were tested using meta-analyses (regression modelling). Where available study measures render analysis unfeasible, narrative review of studies were conducted.

Method

LWSW definition

A significant challenge in accessing LSW literature is the lack of a universally accepted definition, or indeed terminology, to describe roster schedules that employ short sleep/wake rotations. Industry-specific conventions include “watchstanding” (marine), “relay” (rail), “two-up” (rail and road), and “platoon” (emergency services). For the purpose of this review, LSW is defined as “fixed shift work schedules that occur for two or more consecutive days where individuals work for periods not exceeding 8 hours on rosters that allow for an average of more than one sleep period per day”. This definition includes roster schedules such as 6 hours-on/6 hours-off, 8 hours-on/8 hours-off and 4 hours-on/8 hours-off, but excludes those with a single sleep period per 24 hours, such as 12 hours-on/12 hours-off, 16 hours-on/8 hours-off and 8 hours-on/16 hours-off.

Search and inclusion criteria

Based on the above definition, the relevant literature for this review was sourced using PubMed, Embase, PsycInfo and Scopus databases using the keywords “split sleep”, “sustained operations”, “extended operations”, and “continuous operations,” and by inspection of reference lists. Google Scholar was searched with keywords “relay sleep work”, “relay sleep work rail”, “two-up sleep”, “watchstanding sleep”, “police platoon shiftwork sleep”, “4 hours-on 4 hours-off sleep”, “4 hours-on 8 hours-off sleep”, “6 hours-on 6 hours-off sleep”, “8 hours-on 8 hours-off sleep”. The authors also emailed members of the Working Time Society to request any relevant published studies. All relevant papers were available without contact from the authors. Only primary, peer-reviewed articles published in English were included, while studies examining pharmacological interventions were excluded. From this search, we identified 22 papers which examined LSW (17–19, 22–40), two pairs of which overlap (25, 29, 36, 37), leaving a total of 20 independent studies. The identified studies are summarized in table 1. A notable feature of the current literature is the large variation in study design, participant groups/industry, roster schedules and outcome variables – a limitation also noted in systematic reviews of other fields of shift work (41–43).

Schedules and participants

The studies examined in this review employed a range of schedules, which can be broadly divided into: (i) work/rest schedules, such as 4 hours-on/8 hours-off, 6 hours-on/6 hours-off and 8 hours-on/8 hours-off sched-

Table 1. Study characteristics and key results of limited wake shift work (LWSW) studies. Far right columns show evaluation of span of evidence in the studies for the purposes of this review. [SLP=sleep measures (0=not measured; 1=diary; 2=actigraphy; 3=PSG); PERF=performance measures (0=not measured; 1=subjective measurements; 2=objective measurements); SLPY=sleepiness/alertness (0=not measured; 1=subjective measurements; 2=objective measurements); TOT=total of SLP, PERF, and SLPY (possible total=7); CBT=core body temperature; DSST=digit symbol substitution test; ESS=Epworth sleepiness scale; KSS=Karolinska sleepiness scale; MEQ=morningness-eveningness questionnaire; NR=not reported; PANAS=positive affect negative affect schedule; POMS=profile of mood states; PSG=polysomnography; PVT=psychomotor vigilance test; SE=sleep efficiency; SOL=sleep onset latency; SSQ=subjective sleep quality; SSS=Stanford sleepiness scale; SWS=sleep wave sleep; REM=rapid eye movement sleep; TIB=time in bed; TST=total sleep time; VAS-M=visual analog scale of mood].

Study	N, mean (SD) age & range	Operation and schedule	Measures	Design	Results	SLP	PERF	SLPY	TOT
Arendt et al 2006 (26)	14 watch keepers and 12 day workers 25 male, 1 female 37.8 (10.8) years	3-4 week sea journeys Watch keepers 4h-on/8h-off 8 watch keepers rotated shifts by delay weekly	Sleep diary Actigraphy Urinary melatonin	(i) Comparison of day workers and 3 watch-keeping shifts and (ii) comparison of fixed watch schedule with rotating watch schedule	Objective SE and SOL was worse in rotators compared to fixed and day workers, although TST was longer Second sleep was less efficient than main (night) sleep for all watch keepers Sleep similar across all watch schedules. Efficiency <80% for all workers Circadian timing was later in 0000h-0400h watch keepers	2	0	0	2
Condon et al 1984 (35)	9 watch keepers and 3 day workers Age 25-44 years	4h-on/4h-off 24h watch schedule	Oral temperature after several weeks of schedule	Comparison of temperature curve between shift schedules	Oral temperature curve showed adaptation to shift. Earliest acrophase seen in the 04:00h-08:00h/16:00h-20:00h watchkeeping shift workers and day workers. Acrophase was relatively late for 00:00h-04:00h/12:00h-16:00h shift.	0	0	0	0
Condon et al 1988 (27)	19 watch keepers and 20 day workers Age NR	4h-on/8h-off 24h watch schedule	Vector Test Letter Cancellation Test VAS alertness	Compare the type and level of circadian variation in alertness and performance across different shift schedules (04-08/16-20, 12-16/00-04, 08-12/20-24)	Alertness increased from beginning end first shift per day and decreased for second shift. Vector accuracy increased from beginning to end of both shifts. Vector speed showed the same pattern for those working 08-12/20-24 but decreased during the second shift for those on the other schedules.	0	2	1	4
Colquhoun et al 1968 (38)	12 male participants Age NR	4-crew rotating schedule: 4h-on/4h-off/ 4h-on/8h-off/ 4h-on/14h-off/ 4h-on/4h-off	Oral temperature Auditory vigilance test	Description of the circadian rhythms of temperature and performance across a rotating 4-crew schedule for 11-12 days	Temperature rhythm did not show any adaptation across 4 days of this rotating schedule. Auditory vigilance performance closely followed the circadian temperature rhythm. Interpretation of findings limited by reversal of the Day 2 and 3 schedules for half of the sample	0	2	0	2
Colquhoun et al, 1987 (18)	6 watch keepers on a naval ship Age NR	4-day schedule: 4h-on/12h-off/2h-on/10h-off/2h-on/12h-off/4h-on/8h-off/4h-on/12h-off/4h-on/8h-off	Oral temperature Auditory vigilance test VAS alertness Activity log	Description of the sleep, work, performance and temperature rhythms of watchkeepers over a 4-day shift schedule after several months at sea	TST averaged 7.7h per day No obvious changes in temperature rhythm VAS alertness lowest during night watches Daytime alertness lowest following night watches	1	2	1	4
Darwent et al 2008 (22)	10 male train drivers 43.3 (7.4) years; 32-53 years	106h operation 8h-on/8h-off	Sleep diary SSQ Actigraphy PVT	(i) Comparison of sleep environments (home vs. crew van vs. hotel layover) and (ii) comparison of shift rotation (team one commenced duty at 0800-1600h [early] and team two at 1600-2400h [late]) 8-12h layover halfway through the rotation, but due to the variability in layover duration, the start time of post-layover shifts varied between drivers	Cumulative sleep loss not different between rotations but did increase across subsequent trip days TIB, TST & SE lower on early rotation TIB, TST & SE lower in crew van compared to home and layover sites SSQ similar in crew van, at home and layover sites PVT poorer on late rotation PVT constant from shift start to end	2	2	0	4

Continued

Table 1. continued

Author/Date	No, mean (SD) age & range	Operation and schedule	Measures	Design	Results	SLP	PERF	SLPY	TOT
Eriksen et al 2006 (23)	12 male merchant marine and navy navigators 39.0 (NR) years; 26-51 years	66h operation 6h-on/6h-off	KSS Sleep diary	Comparison of shift rotation (team one 0600-1200h and team two 1200-1800h) 2x3h dog watches scheduled half way through the rotation at 1200-1800h resulting in reversal of on- and off-duty patterns	Subjective sleepiness and, likewise, sleep duration was similar for each watch rotation Subjective sleepiness was higher on the night (2400-0600h) than both the day (1200-1800h) and evening (1800-2400h) watches Subjective sleepiness increased from beginning to end of each watch (1200-1800h, 1800-2400h & 2400-0600h) except for the morning watch (0600-1200h) Sleep duration was longer on the morning (0600-1200h) than the day (1200-1800h) off-duty watches and longer on the night than both the day and evening off-duty watches	1	0	1	2
Hansen et al 2011 (34)	577 workers from a Norwegian based shipping company (362 working 6h-on/6h-off, 182 working 12h-on/12h-off). Age NR	6h-on/6h-off	Questionnaire-based survey focusing on sleep and shiftwork	Comparison of 6h-on/6h-off and 12h-on/12h-off roster	Workers on 6h-on/6h-off schedule reported more sleep disturbances than did workers on 12h-on/12h-off schedule. Causes were similar between groups, however, noise affected the 6-h-on/6h-off group more and other factors more greatly affected the 12h-on/12h-off group. No group differences in work capability or safety. Most workers in both groups do not have the same sleep disturbances at home, suggesting disturbances were caused by the work itself.	1	1	0	2
Härma et al 2008 (17)	185 bridge officers 6h-on/6h-off = 45.1 (9.8) years 4h-on/8h-off = 36.9 (9.8) years Other combinations=42.9 (12.3) years	168h 6h-on/6-off (N=45) 4h-on/8h-off (N=68) Other combinations (e.g. 12h-on/12h-off, 4h-on/4h-off, etc) (N=52)	KSS EPS Skogby Excessive Daytime Sleepiness Index Sleep diary	Comparison of (i) shift rotation and (ii) systems 6h-on/6-off team one commenced duty at 0600-1200h and team two at 1200-1800h; and 4h-on/8h-off team one commenced duty at 0000-0400h, team two at 0400-0800h and team three 0800-1200h The last seven days at sea were used in the analyses	6h-on/6-off : TST was similar for both watch rotations 4h-on/8h-off: TST was higher for team one followed by team three then team two watch rotations TST was shorter, frequency of nodding while on duty and excessive daytime sleepiness was higher on 6h-on/6-off compared to 4h-on/8h-off watch systems Time-of-day, time spent awake, and sleep length but not watch system did not significantly predicted sleepiness during watch duty History of snoring was more strongly predictive of excessive daytime sleepiness than watch system	1	0	1	2
Hartley 1974 (24)	36 male soldiers Age NR	96h 8h sleep, 4h sleep & 3x80min naps	Visual vigilance test	Comparison of anchored vs. distributed sleep. Team one had 8h nocturnal sleep (2300h-0700h), team two had 4h nocturnal sleep (0100h-0500h) and team 3 had 3x80min naps (2310h-0030h; 0530h-0650h & 1225h-1345h)	Visual vigilance was higher after 8h nocturnal sleep followed by distributed 3x80min naps then 4h nocturnal sleep	0	2	0	2
Howarth et al 1999 (28)	138 commercial maritime crewmembers. 118 male, 8 female. Mean age 41.8 years.	Commercial crewmembers worked 4h-on/8h-off or 12h-on/12h-off	Sleep diary Items derived from Standard Shiftwork Index and Work-Sleep Survey	Compare severity of sleep problems on-duty and off-duty	When off-duty, commercial crewmembers reported significantly less sleep problems than when on-duty. Sleep length greater while off-duty (478.41 minutes) than while on-duty (441.01 minutes).	1	0	0	1

Continued

Table 1. continued

Author/Date	No, mean (SD) age & range	Operation and schedule	Measures	Design	Results	SLP	PERF	SLPY	TOT
Jackson et al, 2014 (39)	52 healthy male participants 26.51 (4.07) years; 22-40.	19 participants consolidated 10h TIB night time sleep, 17 participants split sleep (TIB 0300-0800 and 1500-2000), 17 participants consolidated 10h TIB daytime sleep	PVT DSST KSS PSG VAS-Mood PANAS	Compare three sleep conditions based on TST, performance and mood.	Participants in the night time sleep condition obtained the most sleep, followed by those in the split sleep condition (greater TST in the morning naps compared to afternoon naps), followed by those in the daytime sleep condition. No significant difference in DSST, PVT lapses or fastest 10% of responses between conditions, however, participants in daytime sleep condition were significantly sleepier than those in split sleep or night time sleep conditions. Participants in split sleep condition had subjectively lower mood than those in the daytime or night time sleep conditions (VAS-Mood). No significant difference in PANAS scores across conditions.	3	2	1	6
Jay et al 2006, 2008 (29, 37)	9 male train drivers 51.3 (6.4) years; 42-63 years	80h operation 8h-on/8h-off	PSG SSQ	Comparison of sleep environments (home vs. crew van vs. hotel layover) Data collapsed across shift rotation	TST per sleep period was higher at home followed by hotel layover then relay van sites After controlling for TST, SE, SOL, REM were similar across sleep sites SWS and subjective sleep quality were lower in relay van compared to layover sites	3	0	0	3
Kosmadopoulos et al, 2014 (40)	29 healthy males 22.5 (2.6).	Forced desynchrony study. 13 participants adhered to a standard sleep-wake schedule (9.33h TIB per 28h) while 16 adhered to a split-sleep schedule (4.67h TIB per 14h).	PVT PSG Core Body Temperature Subjective predicted performance	Comparison of standard sleep-wake schedule to split-sleep schedule	TST did not significantly differ across conditions (regular sleep schedule = 456.6 ± 45.4, split-sleep schedule = 475.4 ± 28.0). No significant difference on any of the PVT metrics across conditions (lapses, slowest 10%, fastest 10%, reciprocal reaction time). No significant difference in subjective predicted performance between conditions.	3	2	0	5
Lamond et al 2005a, 2005b (25, 36)	15 male train drivers 46.6 (4.9)y; 38-56y	Two short (each <48h) operations 8h-on/8h-off	Actigraphy PVT SSS	Comparison of shift rotation (team one commenced duty at 1700-2000h and then recommenced at 0400-1200h [early] and team two at 2000-0400h [late])	TST was lower on the early rotation Subjective alertness prior to a sleep period, TIB and TST declined across subsequent trip days on the early shift rotation, but not late shift rotation PVT performance was constant across subsequent trip days on the early shift rotation, but worse on the final on-duty shift on the late shift rotation	2	2	1	5
Lützhöft et al 2010 (30)	30 watch keepers 29 male, 1 female 45.8 (11.7) years; 27-60 years	6h-on/6h-off (n=15) and 4h-on/8h-off (N=15) Tours ranged from 4 weeks to 6 months	KSS Actigraphy Blink duration Reaction time	Compare 2 watch (6h-on/6-h off) system with a 3 watch (4h-on/8h-off) system	Sleepiness on night shift was higher on 6h-on/6h off schedule Sleepiness increased more across 6h watch than 4h watch No differences in overall sleepiness, TST, SE, reaction time, or blink duration Sleep efficiency was low in both schedules (<80%) Shift length was routinely longer than scheduled, especially for the 6h-on/6h-off schedule (6h48m ± 1h24m vs 4h12m ± 34m)	2	2	1	5
Rutenfranz et al 1988 (44)	38 watch keepers and 29 day workers Age NR	4h-on/8h-off watch 24h watch schedule	Sleep diary	Compare sleep length across different shift schedules (04-08/16-20, 12-16/00-04, 08-12/20-24 and day workers)	Sleep duration was 7.90h per 24h for those working 1200h-1600h/0000h-0400h, 7.56h per 24h for those working 0400h-0800h/1600h-2000h, and 7.20h per 24h for those working 0800h-1200h/2000h-2400h. Day workers averaged 7.51h.	1	0	0	1

Continued

Table 1. continued

Author/Date	No, mean (SD) age & range	Operation and schedule	Measures	Design	Results	SLP	PERF	SLPY	TOT
Sanquist et al 1997 (32)	141 merchant marine personnel Age 43 (11.5) years	N=60 working 4h-on/8h-off schedule Operations ranged 10-30 days	Sleep diary VAS alertness Retrospective alertness inventory	(i) Compare sleep and alertness at sea with that at home, and (ii) compare different watch schedules	38% indicated reduced alertness during watch, but this did not differ between watch types Sleep at sea was less than that at home, 6.6h vs. 7.9h per 24h Those on 0400h-0800h watch obtained less sleep than those on 0000h-0400h or 0800h-1200h watches 0000h-0400h watch had more work periods with low alertness	1	0	1	2
Schaeffer et al 1979 (19)	11 submariners Age NR	6h-on/12h-off watch (N=8) 24h watch schedule (not described, N=3) Multi-week tours	Temperature Pulse rate Respiration rate Blood pressure	Physiological measures compared at beginning and end of tour, and (ii) 18h watch schedule compared to 24h watch schedule	Those on 18h watch schedule, but not the 24h watch schedule, showed 18h physiological cycles as well as persisting 24h cycles Sleep duration decreased from beginning to end of tour, from 6.53h to 5.73h per 24 hours	1	0	0	1
Van Leeuwen et al 2013(33)	30 seafarers 29 men, 1 woman Age 30 (6) years	4h-on/8h-off 24h watch schedule for eight days	PVT EEG KSS Sleep diary	Compare sleepiness across the different teams of workers (team 1: 00-04/12-16, team 2: 04-08/16-20, team 3: 08-12/20-24). Compare performance on first shift of the day to performance during the second shift. Half of the participants worked overtime on days two and three and half on days five and six.	Sleepiness was significantly higher on the first watch of the day than the second. It was highest one hour into watch and lowest at the end of the watch. Sleep on watch occurred more frequently on the first watch of the day compared with the second. Reaction times were fastest on day seven and slowest on day one, except for team 2, whose reaction time was slowest on day seven and fastest on day two. PVT lapses (RT >500ms) occurred more on the first watch of the day than the second.	1	2	1	4

ules (17–19, 25–28, 30–32, 34, 35, 38–40); (ii) work/rest schedules with daytime naps (24); and (iii) work/rest schedules that incorporate a swing shift, "dog" shift, layover or disruption, typically in the middle of a roster schedule (22, 23, 29, 33, 37). Five studies examined 8 hours-on/8 hours-off roster schedules, all of which were conducted with Australian train drivers (22, 25, 29, 36, 37), five examined 6 hours-on/6 hours-off shift schedules, predominantly in ship bridge officers and offshore fleet workers (17, 23, 30, 34, 39), and nine examined 4 hours-on/8 hours-off shift schedules all among maritime watch keepers (17, 26–28, 30–33, 35). The remaining LSW studies employed less common schedules. These included: 4 hours-on/4 hours-off and 4 hours-on/14 hours-off routines among laboratory volunteers simulating a shift work environment; 4 hours-on/12 hours-off, 2 hours-on/10 hours-off and 2 hours-on/12 hours-off routines among ship officers; 6 hours-on/12 hours-off routine among submariners; a split sleep schedule (9.33 hours wake/4.67 hours sleep opportunity) in a forced desynchrony study with volunteers; and an anchor night 4 hours or 8 hours sleep with distributed daytime naps among soldiers (18, 19, 24, 38, 40).

Design and research environment

Eight of the studies identified in this review used a within-subject's design (18, 22, 23, 25, 29, 36–38), ten a between-subject's design (17, 24, 26, 27, 30, 31, 34, 35, 39, 40), and four employed a mixed within- and between-subjects design (19, 28, 32, 33). Seventeen studies were field-based (17–19, 22, 24–32, 34–37) and five used laboratory simulations (23, 33, 38–40).

Measures

A notable feature of the studies identified in this review was the limited overlap of measures, which hindered comparisons. In order to summarize the methodological approaches and assess study quality, a simple scoring key was developed with higher scores indicating higher objectivity (scores are reported in the far right columns of table 1). Specifically, articles were assigned a score for sleep (0=not measured; 1=diary; 2=actigraphy; 3=polysomnographic (PSG), performance (0=not measured; 1=subjective measurements; 2=objective measurements) and sleepiness (0=not measured; 1=subjective measurements; 2=objective measurements)

measurement. The maximum possible score was seven points; however the maximum score achieved by any one study was six points while the modal score was two points. In general, studies focus on one or two domains with only a few more recent studies examining the gamut of sleep, sleepiness and performance, indicating a fertile ground for future research.

Comparing LWSW schedules

To help compare findings between LWSW studies, standardized scores for sleep, sleepiness, and performance were derived. Thirteen studies (17, 22, 23, 25, 26, 28–30, 32, 33, 39, 44) provided data on sleep time, along with sufficient schedule detail to calculate total sleep time per 24 hours, which included data for 25 different crews. In order to perform simple comparisons of average 24 hours total sleep time across roster types and crews, means and standard deviation (SD) from studies were pooled (weighted by sample size, such that each study mean and SD were multiplied by N) across crews to provide roster means and SD, and across studies for the 4 hours-on/8 hours-off rosters to provide crew means and SD within this roster. Analysis of variance (ANOVA) with simple post-hoc comparisons was then conducted to assess differences between rosters and between crews within rosters. In this analysis, it is acknowledged that sleep measures differed between studies, with two studies using PSG (29, 39), four studies using actigraphy (22, 26, 30, 36) and the remaining studies using sleep diaries (17, 28, 32, 33, 44).

Only 12 studies reported performance measures, and of these, 5 reported the psychomotor vigilance test (PVT) (22, 25, 33, 39, 40), and the rest involved other measures of reaction time or vigilance (18, 24, 30, 38), processing speed and memory (27) and subjective performance reports (34, 40). Nine studies reported sleepiness measures, and of these, two reported visual analog scale (VAS) alertness (27, 32), five reported Karolinka Sleepiness Scale (KSS) (17, 23, 30, 33, 39) and the others employed author-generated measures of sleepiness/alertness. Therefore, harvesting of performance or sleepiness/alertness measures from studies to compile for meta-analysis was deemed unfeasible and not pursued. Rather, patterns in performance and sleepiness are summarized in a narrative fashion following meta-analyses of the sleep data.

In order to facilitate testing of our specific hypotheses for the sleep data, a scoring system was constructed. Each crew within each schedule was initially scored using the following equation:

$LWSW\ score = proportion\ of\ nadir\ on\ shift\ (scored\ 0-1) + proportion\ of\ sleep\ opportunity\ in\ WMZ\ (scored\ 0-1) + inconsistent\ timing\ of\ start\ and\ finish\ times\ from\ on\ 24\ hours\ cycle\ to\ the\ next\ (scored\ yes=1,\ no=0) + work-to-rest\ ratio$

Schedules involving (i) more work time during the circadian nadir, (ii) where more of the sleep opportunity falls during the WMZ, (iii) where the timing is inconsistent from one 24-hour cycle to the next, and (iv) the work-to-rest ratio is high will result in higher scores indicating greater likelihood of poor outcomes. For example, for a 00:00 hour crew on a 4 hours-on/8 hours-off schedule, $LWSW\ score = 0 + 0.5 + 0 + 0.5$ with a total of 1, whereas for a 04:00 hour crew, $LWSW\ score = 1 + 0.25 + 0 + 0.5$ with a total of 1.75. We consequently used regression models to test the strength of each predictor, and then the overall score, in predicting the sleep time data. First, work time during the nadir, sleep during the WMZ, changing work/rest timing every 24 hours (yes/no) and work-to-rest schedule were regressed separately against total sleep time per 24 hours for each of the crews, and for each of the schedules (weighted by sample size). Next, a multiple regression was conducted containing all four predictors. Only significant predictors were included in the final model. Results of the multiple regression model were then used to identify significant predictors of total sleep time across studies.

Results

Subgroup meta-analyses

Differences in LWSW schedules and sleep. The shift schedules examined in this review (where schedule timing was provided) are illustrated in the top panel of figure 1. Within each schedule, each line represents a 24-hour period and each crew is represented on a different line, labelled by the start time of the first shift in that 24-hour period. The lower panel displays circadian fluctuations in subjective and objective sleepiness, respectively, and core body temperature, with the circadian nadir and WMZ overlaid across the two panels. Inspection of figure 1 shows a wide variation among shift systems in terms of the time from the beginning of one shift to the beginning of the next, length of shift, and the proportion of time spent on and off shift.

Figure 2 illustrates the mean daily sleep duration for 4 hours-on/8 hours-off, 8 hours-on/8 hours-off and 6 hours-on/6 hours-off studies, labelled according to the start time of the first shift for each crew.

Figure 2 illustrates the impact of the differing LWSW schedules on time spent asleep per 24 hours period. Pooled means across studies yielded an average of 6.9 (SD 1.2) hours per 24 hour period for the 4 hours-on/8 hours-off roster, compared to 5.6 (SD 1.0) hours for the 8 hours-on/8 hours-off and 5.9 (SD 1.5) hours for the 6 hours-on/6 hours-off rosters. ANOVA indicated there were significant

differences between rosters ($F_{2,204}=27.453, P<0.001$), with post-hoc comparisons (LSD) revealing that those on 4 hours-on/8 hours-off rosters obtained significantly more sleep than those on 8 hours-on/8 hours-off or 6 hours-on/6 hours-off rosters ($P<0.01$, with a mean difference of 1.3 hours and 1 hour respectively). Within the 4 hours-on/8 hours-off roster, the difference in sleep duration between crews approached significance ($F_{2,142}=2.460, P=0.089$). Despite this, given the exploratory nature of this analysis, post-hoc comparisons were conducted, which revealed that crews starting at 04:00 hours (who were off-duty between 08:00–16:00 hours and between 20:00–04:00 hours each 24-hour period) obtained significantly less sleep than crews starting at 08:00 hours (and who were off-duty between 12:00–20:00 hours and between 00:00–08:00 hours each 24-hour period). Within the 8 hours-

on/8 hours-off roster, there was a significant difference between studies ($F_{3,49}=5.123, P=0.004$), with train drivers obtaining more sleep on the shorter (48 hours) versus longer (106 hours) return trip, but this may be explained by the 8-hour layover and 3-hour advance in the 8 hours-on/8 hours-off schedule obtained by train drivers on the longer return trip. Although limited to findings from one study by Eriksen et al (23), examination of the 6 hours-on/6 hours-off roster data revealed no significant differences between crews.

For each crew and roster schedule, figure 1 provides an illustration of the proportion of work time coincident with the circadian nadir and rest time with the WMZ. Figure 3 displays the LWSW scores for each crew and roster schedule, represented as a stacked proportion bar graph. The value for each LWSW component is

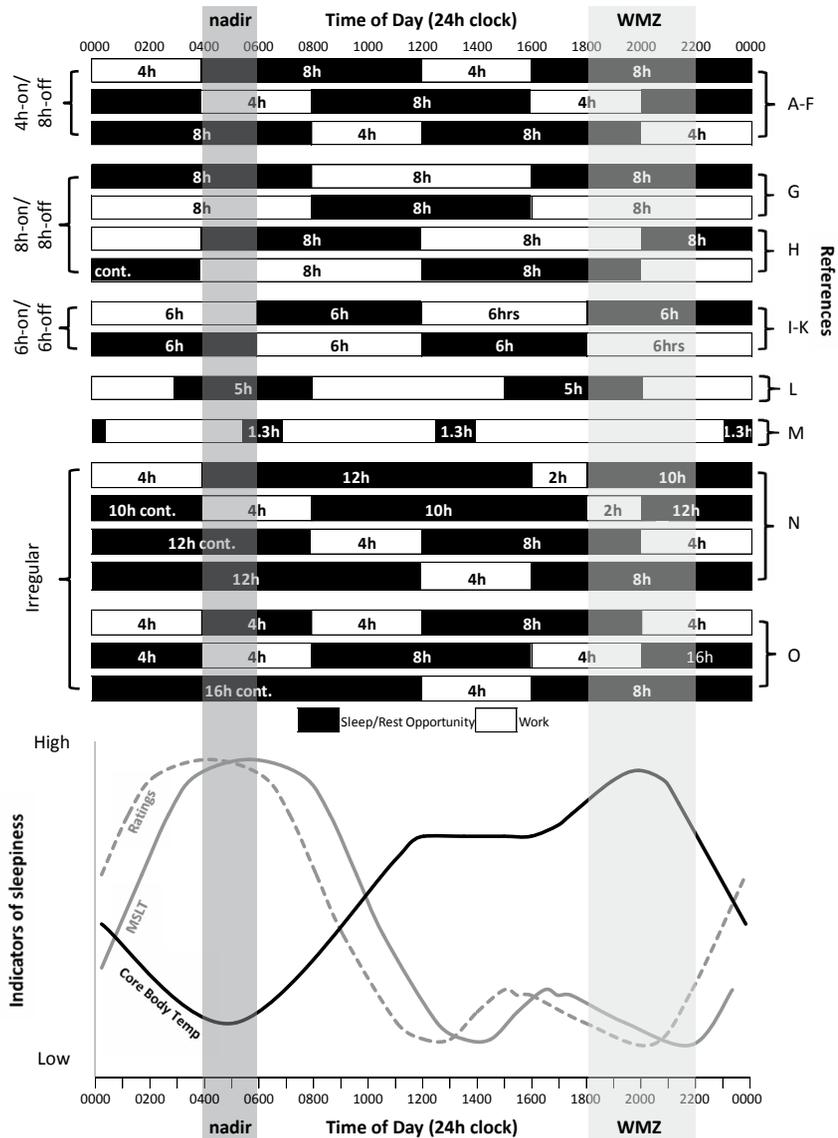


Figure 1. Upper panel: Sleep/rest (black) and work (white) schedules for the studies identified in this review where shift length and timing were provided, classified as 4h-on/4h-off, 8h-on/8h-off, 6h-on/6h-off or Irregular. For the regular roster types, each line represents a separate crew member, with time of first shift start indicated. ^This shift crosses midnight, start time given as midnight for this 24h period. For the irregular rosters (M, N), crew work a staggered start. Lower panel: Circadian fluctuation in subjective sleepiness ratings (Ratings), Multiple Sleep Latency Test time taken to fall asleep (MSLT) and core body temperature (data from Gradisar & Lack, 2004). The circadian low point (nadir) and Wake Maintenance Zone (WMZ) are overlaid across the two panels. References - A: Arendt et al 2006; B: Condon et al 1988; C: Lützhöft et al 2010; D: Rutenfranz et al 1998; E: Sanquist et al 1997; F: van Leeuwen et al 2013; G: Darwent et al 2008; H: Lamond et al 2005; I: Eriksen et al 2006; J: Härmä et al 2008; K: Lützhöft et al 2010; L: Jackson et al 2014; M: Hartley et al 1974; N: Colquhoun et al 1987; O: Colquhoun et al 1968.

presented in different shading, and these are stacked such that the height of the bar represents the total score. Inspection of figure 3 indicates that sleep and performance deficits are greatest for the 8 hours-on/8 hours-off, followed by the 6 hours-on/6 hours-off then the 4 hours-on/8 hours-off schedules. It also reveals that crew start time has a strong impact (eg, scores are higher for 4 hours-on/8 hours-off crews starting at 04:00 hours compared to 00:00 hours and 08:00 hours).

Figure 4 presents results of the regression models of the relationship between the proportion of the nadir at work ($B=-0.66$, $\text{sterr}=0.12$, $t=5.6$, $P<0.001$, $R^2=0.08$), the proportion of sleep in the WMZ ($B=0.39$, $\text{sterr}=0.30$, $t=1.3$, $P=0.19$, $R^2=0.005$), whether the shift start and end times were consistent every 24 hours ($B=-2.00$, $\text{sterr}=0.14$, $t=14.1$, $P<0.001$, $R^2=0.35$) and work-to-rest ratio ($B=-1.82$, $\text{sterr}=0.23$, $t=8.0$, $P<0.001$, $R^2=0.14$) and the 24 hours total sleep time estimates shown in figure 2. All factors except proportion of sleep period in the WMZ were significant predictors of total sleep time in these univariate models, in the hypothesized direction.

The lower panel of figure 4 presents results of the multiple regression model. In the final model, only pro-

portion of the circadian nadir spent at work ($B=-0.51$, $\text{sterr}=0.10$, $\beta=-215$, $t=-5.3$, $P<0.001$) and whether shift start and end times changed every 24 hours ($B=-1.92$, $\text{sterr}=0.14$, $\beta=-0.56$, $t=-13.9$, $P<0.001$) were significant in the final model, such that as these factors increased, sleep duration decreased. The scatterplot of the predicted values from the model (x-axis) against the 24 hours total sleep time values (y-axis) displays the model R^2 of 0.39 (however, the skew in distribution of scores should be noted). This suggests that the crews that experience changing start times (ie, those on the 8 hours-on/8 hours-off roster) appear to be relatively disadvantaged in terms of sleep time, as are those who have a proportion of their nadir on shift (4 hours-on/8 hours-off roster, 04:00 hours crew; and 6 hours-on/6 hours-off roster, 00:00 hours crew).

Narrative review

Exploring variability in sleep duration. While shifts with greater sleep opportunities were associated with more sleep, sleep duration nevertheless varied substantially between studies – even among those with identical shift timing and duration (17, 23, 26, 30, 33, 34). Three

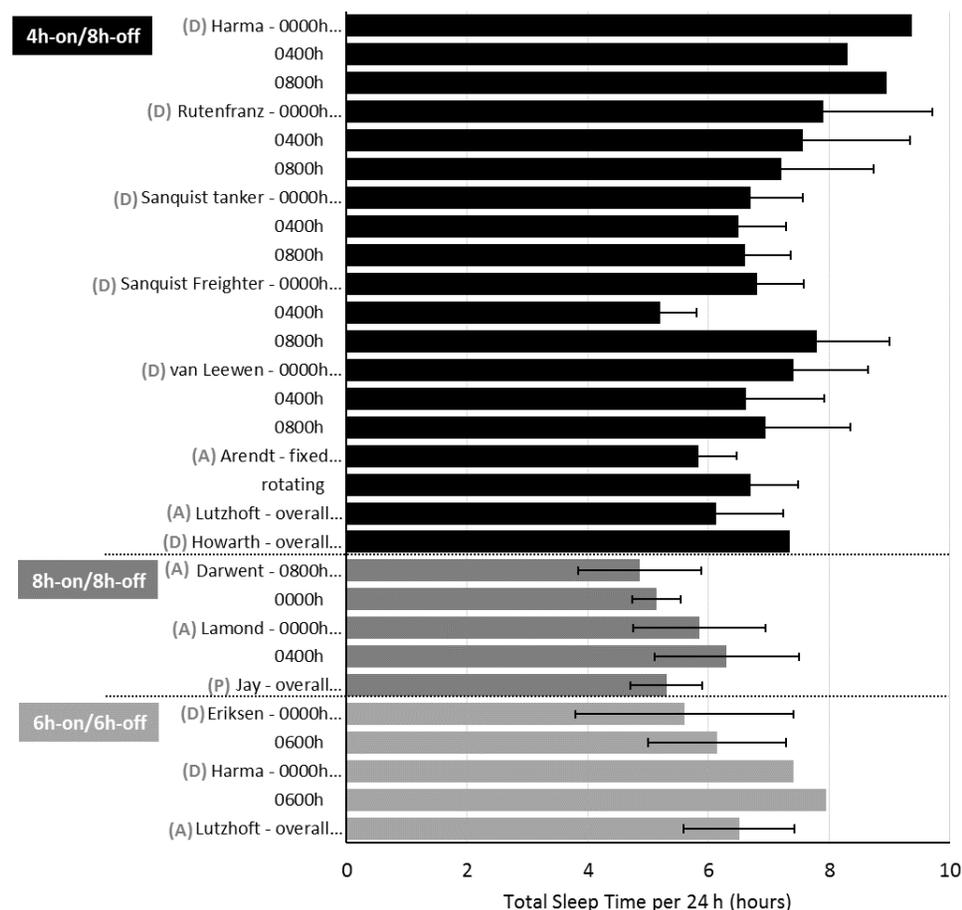


Figure 2. Total sleep per 24h [\pm standard deviation (SD) bars] for each paper. Method of sleep measurement: D=diary; A=actigraphy; P=Polysomnography.

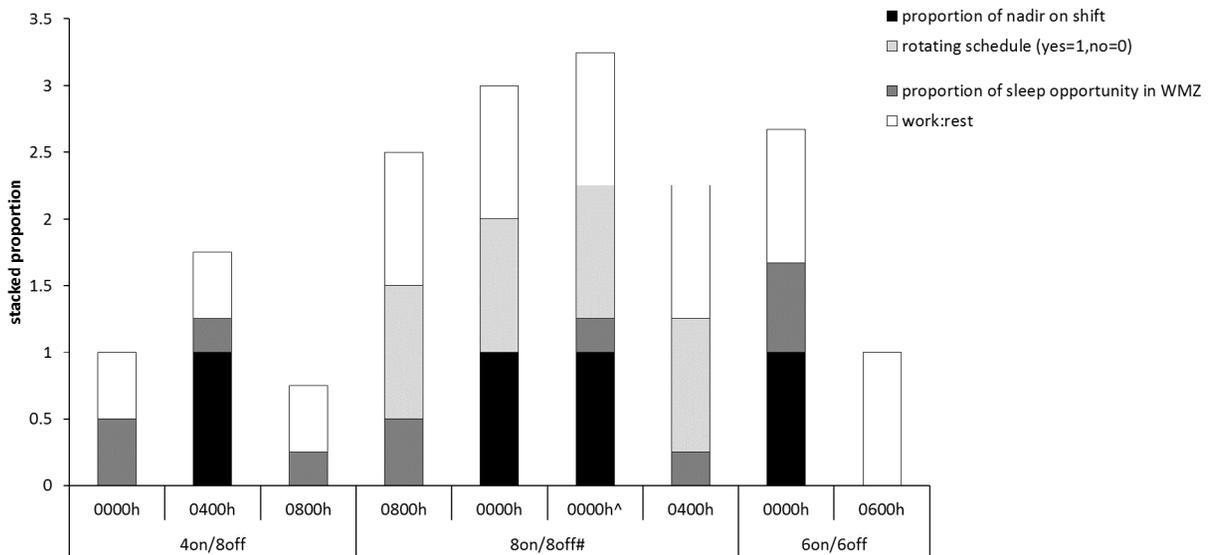


Figure 3. Hypothesized schedule-based factors contributing to sleep loss, sleepiness and performance impairment. Stacked bar graph showing proportion of nadir on shift (black), proportion of sleep period in Wake Maintenance Zone (WMZ) (grey), whether there are changes to the timing of work and rest periods every 24h, (yes/no), and work:rest ratio (white) [stacked proportion=proportion of nadir on shift (0-1) + proportion of sleep opportunity in WMZ (0-1) + 24h timing changes (yes=1, no=0) + work:rest ratio]. Notes: #scores given for first 24h only for the 8h-on/8h-off. Due to the timing changes every 24h for these rosters, in the second 24h, the scores for the 08:00h swap with the 00:00h, and the scores for the ^00:00h swap with the 04:00h. The scores for each crew for the 4h-on/8h-off and 6h-on/6h-off remain the same each 24h period.

factors might account for this variability. First, sleep duration was related to how closely crews adhered to shift start and finish times (30, 34). Lutzhoft (30) found that watch keepers on a 6 hours-on/6 hours-off schedule worked an extra 48 minutes per shift, on average, which significantly eroded their daily opportunity for sleep. Second, sleep duration was related to the quality of LSW sleep environment (eg, ship cabins, submarine bunks, mining "dongas" and train sleeping wagons). Underlying the importance of environmental factors for optimizing sleep, most studies reported that sleep length was shorter on operations compared to either home or layover (22, 25, 29, 32, 36, 45). In their large (N=362) survey of offshore fleet workers, Hansen et al (34) found the most frequently endorsed problems when sleeping at sea were noise (55%), cabin vibration (34%), cabin temperature/humidity (30%), alarms (29%), and poor bedding (21%), all of which were more highly ranked than "bothered by shift work" (18%). Most (81%) did not report similar problems at home. The third factor affecting the reliability of sleep duration estimates and hence making it difficult to compare between studies is the lack of consistency in measures. Since diary measures tend to overestimate sleep duration compared to actigraphy and PSG (46), the lower sleep durations in the 8 hours-on/8 hours-off studies may be at least partially explained by the fact that they relied on objective measures of sleep, while studies examining other rosters commonly used diaries. Only three studies examined the

impact of LSW schedules on PSG sleep parameters (29, 39, 40).

LWSW and sleepiness

Sleepiness was assessed in eight studies, and two trends were evident. First, higher levels of sleepiness tended to be reported in schedules with a longer time-at-work and shorter sleep opportunities. For example, both Härmä et al (17) and Lutzhoft et al (30) reported that sleepiness increased more rapidly and was higher among watch keepers working a 6 hours-on/6 hours-off (ie, 12-hour rest per 24 hours) compared to 4 hours-on/8 hours-off (ie, 16-hour rest per 24 hours) routine. This suggests that, on average, the 4 hours-on/8 hours-off rosters schedule is likely to be better for sleepiness than either the 6 hours-on/6 hours-off or 8 hours-on/8 hours-off rosters. The second trend was the strong circadian variation in sleepiness, with sleepiness peaking at night (17, 23, 25, 30, 32, 33, 36), a finding that is well documented in the circadian literature (47). Taken together, these findings confirm those found in other studies of shift work and/or sleep restriction, namely, that greater sleepiness is experienced during the biological night (47, 48) with increased wakefulness (9, 49) and diminished sleep (50).

LWSW and performance

Half of the studies identified included performance

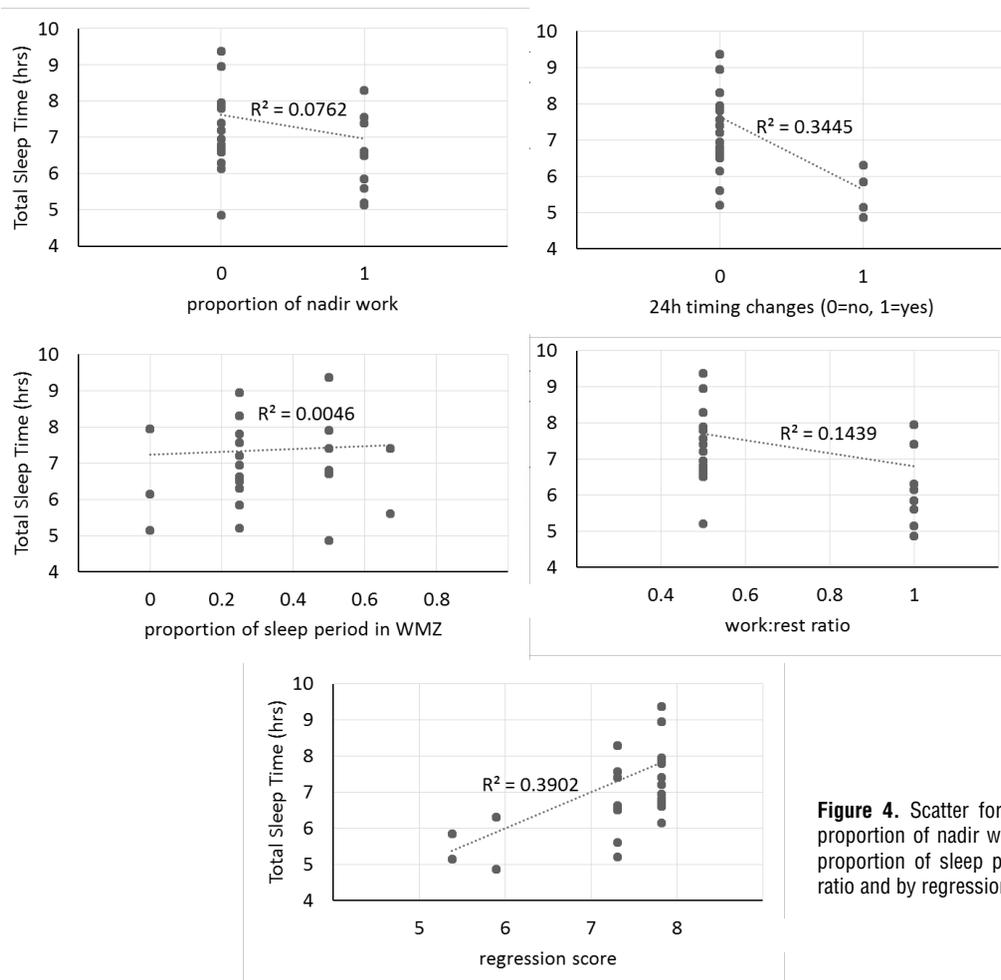


Figure 4. Scatter for sleep times (y-axis) by proportion of nadir work, 24h timing changes, proportion of sleep period in WMZ, work:rest ratio and by regression score.

metrics, with most using the PVT. The PVT is well validated and generates measures of response time (how quickly an individual responds to a stimulus) and lapses of attention (the number of times an individual fails to respond to a stimulus for >500msec) (51). Two studies of Australian train drivers measured PVT lapses shortly before and after shifts (22, 25). Darwent and colleagues (22) report that both PVT response time and lapses were worse among drivers working the late (rested 08:00–16:00 hours, worked 16:00–24:00 hour) compared to early shift (worked 08:00–16:00 hours and rested 16:00–24:00 hours) roster. However, in both roster schedules, performance did not decline from the start to the end of the work cycle. In contrast, Lamond and colleagues (25) report that PVT performance was worse at the end of 8 hours-on/8 hours-off rosters, especially among train drivers working the late roster. Other performance measures, including measures of processing speed and memory (ie, the digit symbol substitution task) and visual vigilance, have also been utilized. The findings suggest that performance on these measures is worse on night shifts and when day sleep is restricted

(24, 52). Hartley demonstrated the potential benefit of splitting one nocturnal period of reduced sleep into three shorter periods spread across 24 hours, with improved performance on visual vigilance (24).

The influence of the circadian system on performance has also been examined by several LWSW groups. Colquhoun et al (53) examined the impact of working either a rotating 4 hours-on/4 hours-off or a fixed 4 hours-on/8 hours-off routine on vigilance and processing speed in a simulation exercise. Performance closely tracked the core body temperature rhythm and, moreover, a shift in the phase of the temperature rhythm was accompanied by a corresponding change in performance. Of interest, however, Kosmadopoulos et al (40) found that split sleep schedules (that roughly approximated a 6 hours-on/6 hours-off shift in a forced desynchrony protocol) resulted in a lessening of the typical performance deficits witnessed around the circadian nadir when compared to a schedule with one consolidated sleep opportunity. They conclude that splitting sleep may blunt both the circadian and sleep homeostatic contributions to performance deficits.

Discussion

The present review has investigated the sleep, sleepiness, and performance implications of LSW routines. Quantitative and narrative analyses of the literature suggest that sleep quality, sleepiness, and performance differ between schedules as well as crews working the same schedule but starting and finishing at different times in the 24-hour cycle. Taken together, the present results align with what we may hypothesize from previous literature, suggesting that schedules with day-to-day timing changes and with a high proportion of the work period during the circadian low, are likely to impact sleep negatively. In addition to these factors, the work-to-rest ratio is likely to influence sleepiness, fatigue and performance. Consistent with this, findings suggest that 4 hours-on/8 hours-off may be superior to both 6 hours-on/6 hours-off and 8 hours-on/8 hours-off shift schedules based on the outcomes considered in this review.

It should be noted that this does not take into account some of the unique considerations of the 4 hours-on/8 hours-off schedules, such as increased staff numbers and frequency of handover. Furthermore, all of the 8 hours-on/8 hours-off rosters involved Australian relay train drivers, while all 6 hours-on/6 hours-off field studies involved the maritime sector. As such, systematic differences among individuals and working environments may account for some of the differences in risk indicators. The applied nature of the research question means that relevant research is always balancing ecological validity and experimental control. Convincing conclusions will ultimately be based on converging evidence from both field studies [eg, (22, 28, 34)] and controlled simulations [eg, (23, 39, 40)]. Therefore, given the inherent differences in research environments, studies would benefit from improved consistency and quality in measures.

LWSW and summary of operational considerations

The operational considerations of the main LSW schedules are summarized in table 2. Taken together, the literature support that LSW shift schedules with a lower proportion of the nadir on shift, lower work-to-rest ratio, and shift schedules that start and end at the same time every 24 hours may be preferable from a sleep, sleepiness, and performance perspective. Interestingly, the degree to which sleep periods occurred during the WMZ was not a significant predictor of sleep obtained per 24 hours. It may be that for the shift schedules reviewed, when sleep opportunities are split in this way, there is sufficient sleep pressure to override the circadian drive for wake during the WMZ. Indeed, in a recent forced desynchrony study involving restricted sleep opportunities, the expected lengthening in sleep

onset latency near the circadian acrophase was extinguished, masking the “forbidden zone” for sleep (54).

Research into traditional shift work shows that, in addition to the length of shifts, the timing of shifts is important in determining outcomes associated with shift work. Even small changes to shift timing can result in improvements or decrements to performance and functioning. Tucker and colleagues found that a one-hour difference in shift start time (07:00–06:00 hours) negatively impacted upon sleep (41). This is yet to be investigated in LSW schedules. A notable feature of the start and end times of the various LSW schedules examined in this review is their relative consistency with start and end times typically falling on even hours and rotations typically anchored at midnight or mid-day. This is especially notable in studies which have examined 4 hours-on/8 hours-off schedules, which all scheduled crews to start shifts at 00:00, 04:00, and 08:00 hours. Since risk factors can be apportioned differently between crews depending on the timing of shifts, there is a need to consider the possible impairments separately for each crew roster.

The considerations outlined in this review necessarily must be balanced by logistic and economic imperatives such as available workforce, salary costs, and the potential implications of increasing the number of staff handovers, which may in turn influence efficiency and safety. Some of these issues are summarized for each schedule in table 2. There are considerations particular to LSW that arise from having more than one sleep period across 24 hours. For example, sufficient time must be given to individuals to prepare for sleep more than once per 24 hours. As such, two break periods incorporating the same time spent off-duty as one longer break period will not afford equal sleep opportunities. Multiple rest periods may also limit the contexts in which this type of shift work system can be implemented, more often being suitable in environments where the sleep quarters are in close proximity to the workplace in order to limit time spent travelling and maximize the sleep opportunity. Of the field studies examined, all encompassed situations where workers slept at the workplace, such as on trains, ships, and submarines. Further, while LSW may offer promise, one limiting factor is the acceptability of LSW to people working them. For example, Sanquist et al found virtually unanimous support among mariners for longer sleep and work periods, as opposed to having sleep split into separate episodes (32). This is likely to be another important reason that this type of shift work is only seen in limited contexts and where individuals are performing safety-critical tasks. To date, Härmä's group are the only LSW researchers to have examined how individual differences affect sleep during LSW. Other factors known to be predictive of

Table 2. Summary of operational considerations for balancing limited wake shift work (LWSW) schedules based on predicted time of day considerations from the literature. These predictions are yet to be directly tested with these schedules.

Roster	Advantages	Considerations
4h-on/8h-off	16h sleep opportunity every 24h Consistent times every 24h	Larger number of staff required Increased number of crew handovers While on average, circadian issues will be lower than the other two rosters, depending on start times, certain crews may be relatively disadvantaged
8h-on/8h-off	Fewer staff required than 4-on/8-off Reduced number of crew handovers	Changing timing every 24h The spread of circadian issues across crew is relatively even Alternating 16h and 8h sleep opportunities every 24h
6h-on/6h-off	Fewer staff required than 4h-on/8h-off Reduced number of crew handovers compared to 4h-on/8h-off 12h sleep opportunity every 24h Consistent times every 24h	While on average, circadian issues will be lower than the 8h-on/8h-off rosters, depending on start times, certain crews may be relatively disadvantaged

general shift work tolerance have yet to be examined in LWSW (54–56).

Review considerations

There are a number of important limitations to this review that must be considered. For example, the review relied upon a relatively small number of studies that involved two main industries. As such, it is not possible to determine whether systematic differences in study population demographics, such as age, weight, health status, or smoking status, have confounded any differences between shift types. The majority of LWSW studies have been field-based with the advantages of ecological validity, but lacking the controls afforded by laboratory-based studies, including the impact of uncontrolled access to caffeine and other stimulants (53). As discussed previously, the effects of a particular schedule are likely to differ depending upon the specific situation and constraints of that environment. Operational environments are likely to differ according to the degree of proscription around sleep, use of time between shifts, characteristics of individuals working within the industry (eg, age, sex, and fitness), working conditions, sleeping conditions, light exposure, stress, and physical and cognitive workload (55, 56). Even within a workforce population there are likely to be differences between workers in terms of sleep, health, smoking status, medication and drug use, caffeine intake, and strategies employed to self-manage shift work (57). This is of particular concern when comparing 8 hours-on/8 hours-off rosters, seen exclusively among long-haul train drivers, with those LWSW shifts, such as the 6 hours-on/6 hours-off and 4 hours-on/8 hours-off schedules worked by mariners. It is also likely that individuals who do not cope with the demands of LWSW schedules leave the industry. Thus, field studies may underestimate the negative effects of these schedules. The studies reviewed also

frequently involve small samples and thus there is some concern regarding statistical power. The lack of uniform terminology to describe these shifts has also meant that identifying relevant literature is challenging and there is a risk that other, suitable studies have not been identified. Finally, it is possible that publication bias may mean that other studies showing non-significant results are not published.

The scoring system presented in this paper was not devised as a biomathematical model of sleep, sleepiness, or performance capacity. Indeed, there are a number of well-developed models that are designed for this purpose (eg, 58–61). Rather, this system was devised to provide a simple method allowing subgroup meta-analysis of the literature across studies that vary greatly in design (without the requirement for biomathematical modelling software). This suggested that the 8 hours-on/8 hours-off schedules for all crews may be more impairing from a sleep perspective than the 4 hours-on/8 hours-off or 6 hours-on/6 hours-off schedules. The regression model explained nearly 40% of the variance in 24 hours total sleep time values. It would have been ideal to validate the scoring system with a second dataset and/or regress it against other outcome values such as sleepiness or performance. Unfortunately, this was not possible with the available data. Further validation and refinement is unquestionably required, however, the current data provide proof of concept that this approach may be used successfully in future similar meta-analyses.

Concluding remarks

The present review identified 22 studies that examined a variety of LWSW roster schedules among >1000 participants. Results suggest that 4 hours-on/8 hours-off schedules offer more promise in terms of maximizing sleep, with likely benefits to sleepiness and performance. From

the range of LSW studies reviewed, several factors can be identified that are associated with improved sleep and performance. These include maximizing the proportion of rest time to work, strictly observing shift start and end times to avoid the erosion of rest breaks, and ensuring that rosters start and end at the same times each 24 hours. By contrast, other factors remain uncertain, in particular whether sleep opportunities spread across the day result in better performance than the same amount of sleep taken in one aliquot, and there are conflicting results from different studies [for example, Hartley (24) versus Mollicone (62)]. Furthermore, while LSW rosters are an established work practice in a number of industries, further evidence is needed to conclude that these rosters lead to increased performance and/or sleep and less sleepiness due to diminished time-on-task and increased sleep opportunities when compared to mainstream rosters. This is a crucial area for future research.

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