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RESEARCH ARTICLE

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Simulated quick returns in a laboratory context and effects on sleep and pre-sleep arousal between shifts: a crossover controlled trial

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ABSTRACT

This trial presents a laboratory model investigating the effect of quick returns (QRs, <11 h time off between shifts) on sleep and pre-sleep arousal. Using a crossover design, 63 participants worked a simulated QR condition (8 h time off between consecutive evening- and day shifts) and a day-day (DD) condition (16 h time off between consecutive day shifts). Participants slept at home and sleep was measured using a sleep diary and sleep radar. Compared to the DD condition, the QR condition reduced subjective and objective total sleep time by approximately one hour (both $p < .001$), reduced time in light- ($p < .001$), deep- ($p = .004$), rapid eye movement (REM, $p < .001$), percentage of REM sleep ($p = .023$), and subjective sleep quality ($p < .001$). Remaining sleep parameters and subjective pre-sleep arousal showed no differences between conditions. Results corroborate previous field studies, validating the QR model and indicating causal effects of short rest between shifts on common sleep parameters and sleep architecture.

Practitioner Summary: This trial proposes a laboratory model to investigate the consequences of quick returns (QRs, <11h time off between shifts) on subjective/objective sleep and pre-sleep arousal. QRs reduced total sleep time, light-, deep-, REM sleep, whereas pre-sleep arousal was unaffected. Results emphasise the importance of ensuring sufficient rest time between shifts.

Abbreviation: QR: Quick return; DD: Day-day; NREM: Non-rapid eye movement; REM: Rapid eye movement; PSG: Polysomnography; TIB: Time in bed; SOL: Sleep onset latency; WASO: Wake after sleep onset; TST: Total sleep time; EMA: Early morning awakening; PSAS: Pre-Sleep Arousal Scale; MEQ: Morning-Evening Questionnaire; LMM: Linear mixed model; EMM: Estimated marginal mean; SD: Standard deviation; SE: Standard error; d: Cohens' d; h: hours; m: minutes

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Quick return; shift work schedule; sleep deprivation; sleep stages; arousal

1. Introduction

Shift work refers to an arrangement of work hours where individuals succeed one another at the workplace, enabling uninterrupted operations for up to 24 h (Costa 2003). To ensure the health and safety of shift workers, the European Parliament and Council (2003) has legislated that time off between two shifts should be at least 11 h. If time between shifts is less, it is referred to as a quick return (QR) (Tucker et al. 2000; Vedaa et al. 2016). According to the European Working Conditions Survey (Eurofound 2017), 23.0% of workers reported having at least one QR last month. In practice, QRs occur in workplaces where employees are assigned to rotating shift schedules typically consisting of day, evening and/or night shifts (Costa 2003; Kecklund and Axelsson 2016). Most commonly, QRs occur when transitioning from working an evening shift to a day shift the subsequent day (Vedaa et al. 2016).

QRs have been associated with several negative consequences for worker's health (Vedaa et al. 2016). This

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includes increased risk of sickness absence (Larsen et al. 2020; Ropponen et al. 2019; Vedaa, Pallesen, et al. 2017), insomnia (Eldevik et al. 2013; Sim et al. 2022) and impaired subjective sleep quality (Dahlgren et al. 2016; Min and Hong 2022). Regularly working QRs is further associated with sleepiness, fatigue, shift work disorder (Eldevik et al. 2013; Flo et al. 2014) and dozing off at work (Vedaa et al. 2019), indicating that QRs have detrimental effects on sleep and functioning. QRs have also been linked to an increased risk of occupational accidents (Nielsen et al. 2019; Vedaa et al. 2019, 2020). As sufficient sleep and restoration is fundamental for health (Itani et al. 2017) and safety at work (Fischer et al. 2017; Folkard and Tucker 2003), a better understanding of how QRs affect workers is warranted.

A variety of methods have been applied to study the effects of shift work, with most being based on epidemiological, prospective field studies and experimental laboratory studies (Kecklund and Axelsson 2016). Laboratory studies can be used to simulate shift work where the influences of confounders (e.g. variation in start/end times of shifts, workload, and work environments) are reduced, and outcome measures (e.g. performance tests or saliva/blood samples) can be administered often and in a timely and accurate manner without interfering with work tasks. Although laboratory contexts in general have been criticised for having less generalisability towards real-life contexts (Holleman et al. 2020), they are still highly valuable when studying causal mechanisms of a given phenomenon (Imai, Tingley, and Yamamoto 2013). To the best of our knowledge, an experimental laboratory model of QR has not yet been constructed. Accordingly, the causal mechanisms of QRs on sleep remain uninvestigated.

To validate a laboratory model of QRs, it is important to replicate previous field studies that examined QRs and sleep. Previous studies have demonstrated that QRs are associated with curtailed sleep (Ganesan et al. 2019; Vedaa et al. 2016; Vedaa, Mørland, et al. 2017), which seems reasonable considering that the time between two shifts in a QR is commonly restricted to 8h - 9h (Vedaa et al. 2016). Previous studies on QRs and sleep have primarily investigated subjectively reported sleep parameters and actigraphy recordings. The effects of QRs on objective sleep measures such as sleep architecture has not yet been investigated in field nor in laboratory contexts.

A night of sleep is characterised by the brain alternating between NREM- (non-rapid eye movement) and REM (rapid eye movement) sleep in about 90-minute cycles. Deep restorative sleep (N3) predominates the first sleep cycles before gradually decreasing. Conversely, light sleep (N1/N2) and REM sleep predominate in the later parts of the main sleep period (Carskadon and Dement 2005). As QRs are expected to shorten sleep duration, a viable hypothesis is that sleep in these shift transitions terminate before sufficient quantity of light- and REM sleep is obtained. This is consistent with the result of previous polysomnography (PSG) studies in where time in bed (TIB) is restricted. In these studies, slow wave activity during NREM sleep remain largely unaffected, whereas N1, N2, and REM sleep decrease already from the first night of sleep restriction (Belenky et al. 2003; Brunner, Dijk, and Borbély 1993; Elmenhorst et al. 2008; Van Dongen et al. 2003). Similar findings have also been reported following night work, where daytime sleep duration is reduced by 2 h–4 h compared to nocturnal sleep, and where the discrepancy mainly comprises reductions in N2 and REM sleep (Åkerstedt 2003).

QRs have been associated with difficulties unwinding after the evening shift (Dahlgren et al. 2016; Öster et al. 2022) and higher levels of self-rated stress during work weeks consisting of QRs (Dahlgren et al. 2021). Another study found that sleep onset latency (SOL) was prolonged after the evening shift during QRs, compared to between two consecutive day shifts. This might indicate elevated levels of arousal when attempting to fall asleep during QRs (Vedaa, Mørland, et al. 2017). Rumination regarding events at work and concerns about the work situation on the coming shift may impair unwinding before bedtime during real-life QRs (Epstein et al. 2020). However, it is unclear whether arousal is caused by recent occurrences at work, worry about upcoming work, or due the short time off between the shifts causing stress in terms of obtaining sufficient sleep. As the present trial was conducted in a controlled laboratory setting manipulating time off between the simulated shifts, it is likely that potential arousal will be induced in terms of the latter point. It is therefore warranted to investigate whether restricted time off between shifts during QRs may cause higher levels of pre-sleep arousal.

The present trial aimed to replicate field studies on QRs and sleep, to provide validity to the QR model and indicate causal effects of short time off between shifts on sleep. Secondly, the trial aimed to provide data on the currently unexplored effects of QRs on sleep architecture (effects on sleep stages). Thirdly, the trial aimed to investigate subjective arousal level prior to bedtime to assess potential arousal associated with sleep in a laboratory QR context. Based on the first aim, it was hypothesised that a QR condition with a restricted 8h time off between an evening and a consecutive day shift would cause sleep to be curtailed, compared a DD (day-day) condition with a 16h time off between two consecutive day shifts. It was further hypothesised that light (N1/N2)- and REM

sleep would be reduced, whereas deep sleep (N3) would remain more or less unaffected in the QR condition compared to the DD condition. Lastly, the third hypothesis posited that the restricted time off during the QR condition would cause increased subjective pre-sleep arousal, due to the anticipation of inadequate time for unwinding relative to in the DD condition.

2. Materials and methods

2.1. Participants

Participants were recruited from flyers/posters and pitches in lectures at the University of Bergen campuses and from an elective course offered to students across all study programs, where students obtain course credits by participating in different research projects. Upon completion of the trial, participants recruited from the elective course received course credits, while students recruited elsewhere were offered a financial reward of approximately 200 USD. The option to choose between the financial reward or course credits was available to participants taking the course, however no one opted for this. To sign-up, participants completed an initial online screening questionnaire including questions related to the inclusion and exclusion criteria. The following inclusion and exclusion criteria were employed: 19–50 years of age, being physically/mentally healthy and having proficiency in Norwegian. Health status was assessed using a questionnaire that covered sleep disorders, psychiatric or neurological disorders, as well as heart diseases. Exclusion criteria were extreme morning/eveningness types, pregnancy, and use of medications that could affect sleep/cognitive functions. Participants were instructed to refrain from alcohol consumption during participation and to maintain habitual nicotine and caffeine usage. Seventy-eight participants were enrolled in the current trial (signed informed consent). Of these, five withdrew after enrolment, one group of six participants had to be cancelled due to COVID-19, and one participant was excluded due to non-compliance with the trial protocol. Three participants were further excluded from the analyses due to missing data (see Figure 1). The trial was approved by the Norwegian Regional Committee for Medical and Health Research Ethics (identifier: 234184) and pre-registered at ClinicalTrials.gov (identifier: NCT05162105).

2.2. Trial design

QRs were simulated in a laboratory context using an experimental cross-over design. Each participant worked in total four simulated shifts, consisting of one simulated evening shift (15:00 h – 23:00 h) and three simulated day shifts (07:00 h – 15:00 h). The shifts were organised into two conditions; an evening shift

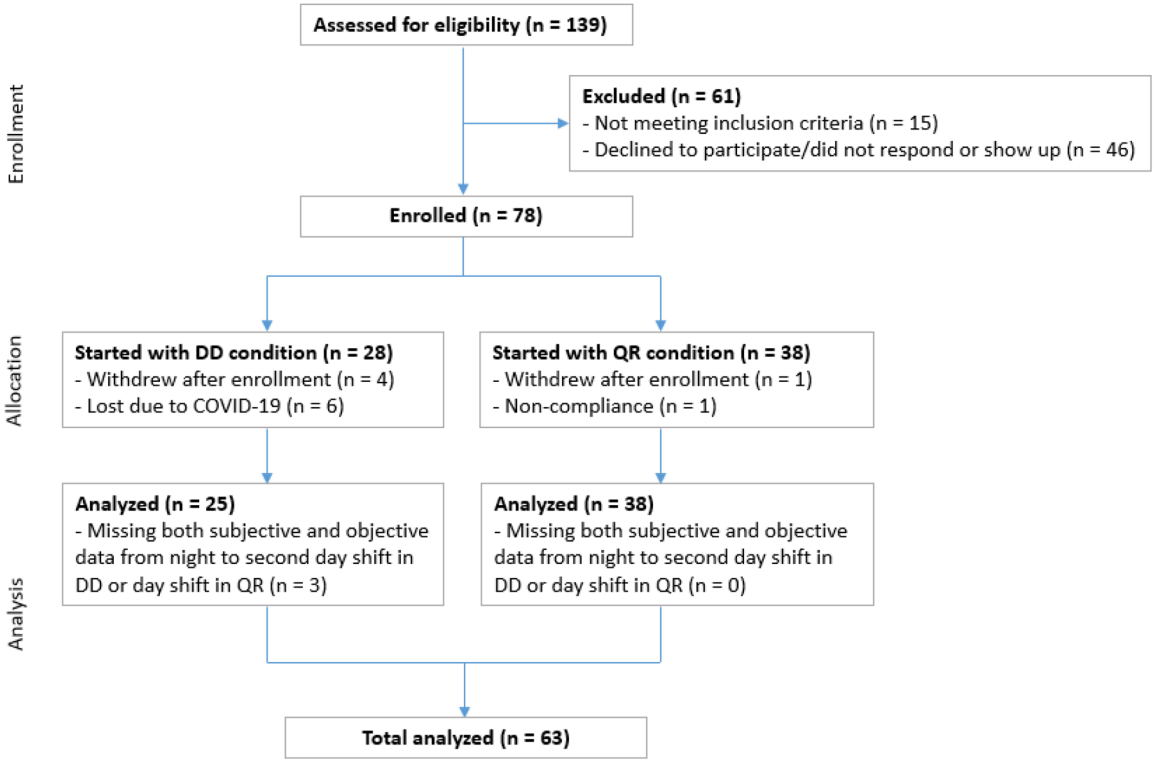

Figure 1. Flow chart showing the number of participants from recruitment to analysis. DD: day-day and QR: quick return.

followed by a day shift (QR condition, 8 h time off between shifts) and a day shift followed by a day shift (DD condition, 16 h time off between shifts). Between the two conditions, there was a wash-out period of at least 14 days. Each participant recorded in total six nights of sleep at home; two baseline nights (first night in each condition), one night prior to the first day shift in the DD condition, one night prior to the evening shift in the QR condition, one night between shifts in the DD condition, and one night between shifts in the QR condition (see Figure 2).

2.3. Trial procedure

Prior to the first baseline night, participants attended an enrolment meeting where they signed an informed consent form and completed questionnaires regarding relevant background variables (age, sex, contraceptives and circadian preference). They were also given instructions on how to complete the sleep diary, the Pre-Sleep Arousal Scale (PSAS), and how set-up the sleep recording device (sleep radar) at home. Participants were spread across 14 groups (half starting with the QR/DD condition), with each group having between 1 and 14 participants. As the experiment required mandatory attendance of approximately 34 h in the laboratory, primarily during daytime hours (16 h for each condition across consecutive days and 2 h for enrolment meetings), it was challenging to match attendance with the private schedule of the participants. To increase acceptance of participation, participants could choose between groups completing the experiment on pre-defined dates, hence random allocation of participants to the order of the two conditions was compromised and the wash-out period was reduced to minimum 14 days. All data was collected in Norway, Bergen, between September 2021 and March 2023.

2.4. Measurements

The Morning-Evening Questionnaire (MEQ) consists of 19 items where a composite score of all items is calculated (range 16–86) and used to classify each participant into either definitely evening (range 16–30), moderate evening (range 31–41), intermediate (42–58), moderate morning (59–69) and definitely morning (70–86) (Horne and Ostberg 1976). Extreme morning and evening types applied in the exclusion criteria were defined as having a score of 78–86 (upper half of definitely morning classification) or 16–24 (lower half of definitely evening classification).

Subjective sleep was measured with the Consensus Sleep Diary (Carney et al. 2012), across the six nights. It contains questions regarding time entering bed, time wanting to sleep (lights off/intention to sleep), sleep onset latency (SOL), time of final awakening, time getting out of bed, wake after sleep onset (WASO), and sleep quality (assessed on a scale from 1 = very bad to 5 = very good). Total sleep time (TST) was calculated as the interval between the time wanting to sleep and time of the final awakening, subtracted by the SOL and the WASO. Sleep efficiency was calculated by dividing the TST by the total amount of time spent in bed (TIB) multiplied by 100. Early morning awakening (EMA) was calculated as the interval between time of the final awakening and the time getting out of bed. Questions regarding the time entering bed and wanting to sleep were completed before lights off/intention to sleep and the remaining questions after leaving the bed.

The Pre-Sleep Arousal Scale (PSAS) (Nicassio et al. 1985) was completed prior to lights off/intention to sleep. The PSAS contains 16 items, each rated on a scale from 1 (not at all) to 5 (extremely). A sum score of the first eight items constitutes a somatic arousal subcategory (range 8–40) and the remaining eight items constitutes a cognitive arousal subcategory (range 8–40). Higher composite scores indicate higher pre-sleep arousal (see supplementary Table 2).

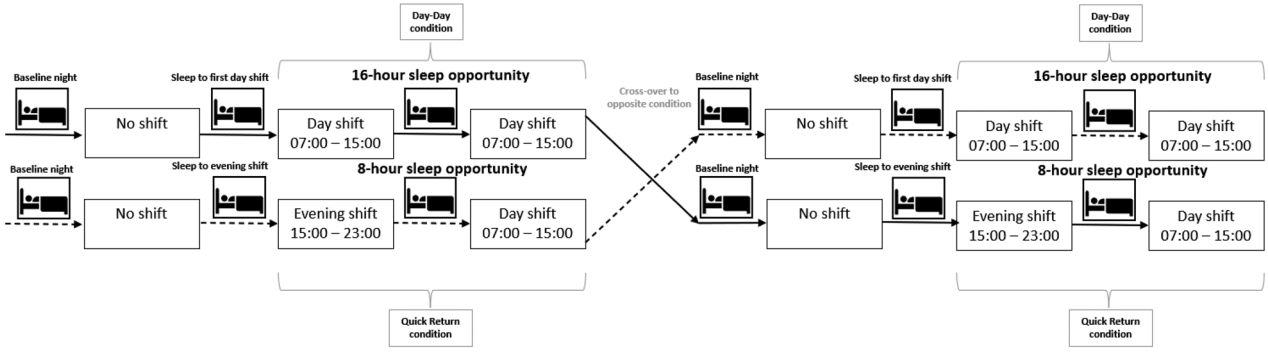

Figure 2. Flow chart of the trial design. Solid arrows indicate starting in the DD condition, followed by crossing over to the QR condition. Stapled arrows indicate starting in the QR condition followed by crossing over to the DD condition.

Objective sleep was measured using a sleep radar, which is a novel method for studying sleep and wakefulness (Somnofy XeThru, VitalThings, Norway). The device detects light and emits electromagnetic impulses of ultra-wideband signals that are reflected back to the device upon hitting denser materials (i.e. human body). Due to accurate detection of changes in stimuli, the device is able to determine movement (such as respiration due to chest movement) of the person sleeping. Comparing ultra-wideband signal devices with polysomnography (PSG) has indicated high accuracy, with a difference of −5.7 min and 1.5 min for SOL and TST (Pallesen et al. 2018), respectively, and an accuracy of 74% for N1 and N2 (light sleep), 78% for N3 (deep sleep) and 78% for REM sleep (Toften et al. 2020). In this trial, the following sleep radar parameters are reported: TST, sleep efficiency, time wanting to sleep (time from lights-off or the last time the participant entered the range of the radar, to the first time the radar classified the participant as being asleep), SOL, time of final awakening, EMA (interval between time of final awakening and disappearing from the range of the sleep radar), WASO and the sleep stages. The sleep stages were analysed using the variables time in light-, deep- and REM sleep, in addition to the percentage of time in each sleep stage.

2.5. Statistical analyses

TST, sleep efficiency, bedtime, SOL, time of awakening, EMA, and WASO from both the sleep diary and radar data were analysed. Additionally, subjective sleep quality measured with the sleep diary, and total time and the percentages spent in light-, deep- and REM measured with the sleep radar were analysed. From the PSAS, the somatic and cognitive subcategories were analysed. Linear mixed models (LMMs) were run on the outcomes. Assumptions of normal distribution and equal variance of residuals were checked for each model by inspection of QQ-plots and histograms. Equivalent analyses using LMMs were also performed descriptively to report means and standard errors for baseline nights, night to first day shift in the DD condition, and to the evening shift in the QR condition. For all LMMs, 'condition' (with levels 'night between day shifts in DD condition' and 'night between evening and day shifts in QR condition') was set as the fixed effect, and 'participant intercept' as a random effect. The slope was not included as each participant had only one night of sleep between the shifts in each condition, which rendered it insufficient to calculate the random slope variance (Barr et al. 2013; Brauer and Curtin 2018). Statistical significance was concluded if there was a significant effect of condition ($p < .05$). Analyses were run in RStudio (version 4.1.1), using the lme4 package (version 1.1–27.1) to define the LMMs, and the emmeans package (version 1.7.2) to calculate estimated marginal means (EMMs) and Cohen's *d*.

The sample size calculation was based on Vedaa, Mørland, et al. (2017), expecting a small to medium effect on TST. When setting the effect size (*d*) to .40, power to .80, and the correlation between measures to .50, the power analyses show that 60 subjects are needed.

3. Results

3.1. Participant descriptives, baseline sleep, and sleep prior to first shifts in the DD/QR conditions

Data from 63 participants were analysed, comprising sleep diaries and radar data from 62 and 54 participants, respectively. The mean age was 23.7 ($SD = 5.6$) years and most participants were women ($n = 50$, 79.3%). Of them, 44 (86.0%) used contraceptives. None of the participants were categorised as definitely morning types, whereas 12 (19.0%), 35 (55.6%), 14 (22.2%), and 2 (3.2%) participants were defined as moderate morning-, intermediate-, moderately evening-, and definitely evening types, respectively. In the sleep diary data (subjective sleep) from baseline nights prior to the start of the experiment (Table 1), the TST, time wanting to sleep, SOL, time of final awakening, and EMA were similar between the DD- and QR conditions and QR conditions and indicated good sleep. On average, sleep during the

Table 1. Descriptive analyses from the sleep diary during baseline nights and the nights prior to first shifts in the quick return- and day-day conditions.

	Total sleep time (hh:mm)	Time wanting to sleep (hh:mm)	Sleep onset latency (m)	Time of final awakening (hh:mm)	Early morning awakening (m)
Day-day condition					
Baseline (mean (SE))	07:41 (00:11)	00:10 (00:10)	27.9 (3.1)	08:23 (00:14)	31.3 (4.5)
Night to first shift (day shift, mean (SE))	05:40 (00:09)	23:31 (00:11)	34.9 (5.2)	05:52 (00:04)	5.4 (0.6)
Quick return condition					
Baseline (mean (SE))	07:18 (00:08)	00:13 (00:12)	27.8 (3.7)	08:08 (00:12)	26.1 (4.2)
Night to first shift (evening shift, mean (SE))	07:33 (00:14)	00:18 (00:11)	28.2 (4.3)	08:24 (00:13)	45.9 (17.1)

Note. h: hour; m: minutes.
Means and standard error (*SE*) are reported.

night prior to the first day shift in the DD condition was shorter relative to baseline sleep, as seen by a shorter TST. Sleep parameters during the night prior to the evening shift were on average similar to baseline nights in the QR condition. The remaining parameters from the sleep diary and sleep radar during baseline sleep and sleep prior to the first shifts in the DD- and QR conditions are reported in the supplementary materials (supplementary Table 1).

3.2. Comparing the night between the QR and the DD conditions

In the sleep diaries (Table 2), participants reported shorter TST and worse sleep quality in the QR condition compared to the DD condition. No significant differences were observed for the remaining subjective sleep parameters. Results from the sleep radar (objective sleep, Table 3) showed later bedtime and reduced TST in the QR condition compared to the DD condition. In the QR condition, participants also spent less time in light-, deep- and REM sleep relative to the DD condition. When considering the percentage of each sleep stage relative to TST, only REM sleep was significantly reduced. No differences were observed in the remaining objective sleep parameters.

3.3. Pre-sleep arousal scale the nights between shifts

The results showed no significant differences in neither somatic arousal prior to bedtime between the QR- (EMM = 11.6, SE=0.5) and DD conditions (EMM = 11.4, SE=0.5, F(1, 59) = 0.13, p=0.123/d=−0.07), nor in cognitive arousal between the QR- (EMM = 14.2, SE=0.8) and DD conditions (EMM = 13.9, SE=0.8, F(1, 58) = 1.68, p = .683/d=−0.08). The analyses of each item in the instrument are presented in supplementary Table 2.

4. Discussion

This trial applied a simulated laboratory model of QRs to examine the causal effects of short time off between shifts on subjective (sleep diary) and objective (sleep radar) sleep, in addition to subjective pre-sleep arousal. The first hypothesis was supported, where shorter time off between shifts in the QR condition (8h time off) curtailed sleep, relative to between shifts in the DD condition (16 h time off). This was evident in both subjective and objective data showing a significant reduction in TST, which is in line with previous findings from field studies where sleep is curtailed during QRs (Ganesan et al. 2019; Vedaa et al. 2016; Vedaa, Mørland, et al. 2017). This trial is therefore the first to demonstrate a causal relationship between shortened time off between shifts during QRs being a determinant of curtailed sleep.

Regarding SOL, EMA and WASO, no differences were observed between the two conditions in neither subjective nor objective sleep data. One previous field study measuring sleep by diaries found less EMA and WASO during QRs (Vedaa, Mørland, et al. 2017), suggesting that as bedtime was delayed and sleep duration was curtailed, the sleep period was assumingly centred during the earlier part of sleep with a larger presence of deep sleep. A possible explanation for why the current trial found no differences between the QR- and DD conditions for EMA and WASO could be the early start of the day shifts. Shifts starting before 09:00h have been shown to curtail sleep (Ingre et al. 2008) and as the DD condition had two consecutive day shifts, starting at 07:00 h, participants may have been sleep deprived already after the night prior to the first day shift. This is supported by TST on average being approximately 1.5 h–2.0 h shorter prior to the first day shift in the DD condition, relative to the baseline measurements. As most participants were students, it should also be noted that lectures started no sooner than at 08:15 h, which is considerably later than

Table 2. Estimated marginal means (EMM) and standard error (SE) of sleep diary parameters for nights between the two shifts in the DD (day-day) and QR (quick return) conditions.

Sleep parameter	Night between the day shifts (DD)	Night between evening- and day shifts (QR)		
Sleep diary	EMM (± SE)	EMM (± SE)	$F(df)$, p	d
TST (hh:mm)	06:05 (00:09)	04:59 (00:09)	**$F(1, 59)=31.29$, $p<.001$**	1.03
Sleep efficiency (%)	85.2 (1.2)	85.7 (1.2)	$F(1, 58)=0.07$, $p=.779$	−0.05
Time wanting to sleep (hh:mm)	00:14 (00:19)	00:14 (00:19)	$F(1, 59)=0.38$, $p=.539$	−0.11
SOL (m)	23.3 (3.7)	27.2 (3.7)	$F(1, 61)=0.64$, $p=.426$	−0.23
Time of final awakening (hh:mm)	05:52 (00:04)	05:54 (00:04)	$F(1, 61)=0.69$, $p=.543$	−0.11
EMA (m)	6.8 (1.0)	6.8 (1.0)	$F(1, 61)=0.01$, $p=.923$	0.02
WASO (m)	5.5 (1.4)	3.8 (1.4)	$F(1, 61)=0.78$, $p=.381$	0.16
Sleep quality (1–5)	3.4 (0.1)	2.9 (0.1)	**$F(1, 61)=12.2$, $p<.001$**	0.63

Note. TST: total sleep time; SOL: sleep onset latency; EMA: early morning awakening; WASO: wake after sleep onset; h: hour; m: minutes; d: Cohen's d. Bold values indicate a significant difference between the DD- and QR conditions (p <.05).

Table 3. Estimated marginal means (EMMs) and standard error (*SE*) of sleep radar parameters for nights between the two shifts in the DD (day-day) and QR (quick return) conditions.

Sleep parameter	Night between the day shifts (DD)	Night between evening- and day shifts (QR)		
Sleep radar	EMM (± *SE*)	EMM (± *SE*)	*F*(*df*), *p*	d
TST (hh:mm)	05:46 (00:08)	04:50 (00:08)	**$F(1, 53) = 36.88$, $p < .001$**	1.17
Sleep efficiency (%)	85.3 (1.2)	84.6 (1.2)	$F(1, 53) = 0.31$, $p = .579$	0.11
Time wanting to sleep (hh:mm)	23:18 (00:08)	00:18 (00:08)	**$F(1, 53) = 46.12$, $p < .001$**	−1.31
SOL (m)	30.4 (3.0)	32.6 (3.0)	$F(1, 53) = 0.36$, $p = .554$	−0.12
Time of awakening (hh:mm)	05:51 (00:04)	05:52 (00:04)	$F(1, 53) = 0.17$, $p = .678$	−0.08
EMA (m)	8.8 (1.2)	6.5 (1.2)	$F(1, 53) = 2.65$, $p = .110$	0.31
WASO (m)	20.1 (2.6)	15.0 (2.6)	$F(1, 54) = 2.00$, $p = .163$	0.27
Time in light sleep (hh:mm)	03:06 (00:05)	02:43 (00:05)	**$F(1, 53) = 12.53$, $p < .001$**	0.68
Time in deep sleep (hh:mm)	01:17 (00:03)	01:06 (00:03)	**$F(1, 53) = 9.01$, $p = .004$**	0.58
Time in REM sleep (hh:mm)	01:23 (00:04)	01:02 (00:04)	**$F(1, 53) = 24.91$, $p < .001$**	0.96
Light sleep (%)	53.7 (1.0)	56.0 (1.0)	$F(1, 53) = 2.71$, $p = .103$	−0.32
Deep sleep (%)	22.6 (0.9)	23.1 (0.9)	$F(1, 53) = 0.16$, $p = .694$	−0.08
REM sleep (%)	23.6 (0.9)	20.9 (0.9)	**$F(1, 53) = 5.50$, $p = .023$**	0.45

Note. TST: total sleep time; SOL: sleep onset latency; EMA: early morning awakening; WASO: wake after sleep onset; REM: rapid eye movement; h: hour; m: minutes; *d*: Cohen's *d*. Bold values indicate a significant difference between the DD- and QR conditions ($p < .05$).

the start of the day shift in this trial. Thus, a homeostatic build-up during the DD condition may have interfered with the effects of having one night of curtailed sleep the night prior to the day shift in the QR condition. However, as there is currently only one published field study examining variables other than sleep duration in relation to QRs (Vedaa, Mørland, et al. 2017), less is known in terms of how sleep parameters other than sleep duration are typically affected between two day shifts and QRs. As our finding of reduced TST during QRs largely aligns with the current findings from previous field studies, it seems that simulating short rest times in a laboratory setting has a similar effect on sleep as found in field settings. Thus, providing validity to the QR laboratory model.

The second hypothesis was supported in terms of light- and REM sleep being reduced in the QR- relative to the DD condition. This was evident by time spent in light- and REM sleep, and the percentage of REM sleep. REM sleep is considered important for several aspects of human health and functioning. Walker and van Der Helm (2009) postulated the 'sleep to forget and sleep to remember' hypothesis, proposing that REM sleep serves a 'therapeutic' function by reactivating emotional experiences during sleep, to dampen the emotional valence associated with them. Having reduced REM sleep due to QRs could potentially be linked to impaired dampening of emotional valence related to events at work, which may further be associated with reduced mental health among shift workers (Torquati et al. 2019) and particularly for irregular work schedules (Zhao et al. 2019). Although, one study found that QRs were not associated with symptoms of depression or anxiety (Eldevik et al. 2013). REM sleep is also thought to play a role in maintaining cognitive performance (Rasch and Born 2013; Schäfer et al. 2020), which can be seen in coherence with heightened risk of occupational accidents in association with QRs (Nielsen et al. 2019; Vedaa et al. 2019; Vedaa, Pallesen, et al. 2017).

Surprisingly, a reduction in deep sleep in the QR- relative to DD condition was not in line with the second hypothesis. This was evident in terms of time spent in deep sleep. This finding is contradictory to sleep restriction paradigms where shortening TIB usually does not affect slow wave sleep (Belenky et al. 2003; Brunner, Dijk, and Borbély 1993; Elmenhorst et al. 2008; Van Dongen et al. 2003) and sleep architectural changes during shortened daytime sleep following night work, where deep sleep is unaffected (Åkerstedt, 2003). It is however important to note that the sleep stages measured in the present trial were based on radar technology and not polysomnography. Although the sleep stages of the radar has been calibrated to and validated against polysomnography (Toften et al. 2020), sleep architecture data in the present trial is not directly comparable to in sleep architecture data in previous research. Moreover, the sleep radar has not yet been validated against sleep restriction interventions (Pallesen et al. 2018; Toften et al. 2020).

Assuming a valid reduction in deep sleep, a possible explanation could be linked to the participants sleeping approximately 2.0 h longer prior to the evening shift in the QR condition, compared to before the first day shift in the DD condition. Therefore, participants may have had less sleep propensity after the evening shift, resulting in less deep sleep the night to the day shift in the QR condition. Another explanation could also be due to the circadian modulation of REM sleep, where higher amounts of REM sleep occur if the sleep episode is centred close to the circadian nadir

(Dijk and Czeisler 1995). As participants attempted to sleep an hour later in the QR- relative to the DD condition in the sleep radar data, the sleep periods were likely centred at a later circadian timing causing REM sleep to be more prioritised relative to deep sleep. Lastly, despite REM/light sleep being more prominent in the later parts within a sleep period, occasional short deep sleep episodes may also occur at this point (Gagnon, De Koninck, and Broughton 1985; Webb and Agnew 1967). Thus, the additional TST in the DD condition compared to the QR condition may have provided additional short episodes of deep sleep.

The third hypothesis was not supported, as the PSAS subscales showed similar arousal values in both conditions. It may however be questioned whether the Pre-Sleep Arousal Scale is an appropriate tool for measuring arousal in a QR context as the single item 'worry about falling asleep' (supplementary Table 2) displayed significantly higher worry in the QR condition compared to the DD condition. The items of the PSAS subscale may therefore not be as sensitive to arousal regarding shift work compared to clinical populations for which it was initially developed. On the other hand, no heightened pre-sleep arousal may suggest that having short time off between shifts in itself is not the major determinant for difficulties unwinding during QRs. Instead, the lack of unwinding during QRs could be more dependent on events and responsibilities only present in real-life work contexts.

4.1. Strengths, limitations and further directions

A limitation of the present trial is that the participants were not familiar with shift work. Attempts were made to recruit shift workers and healthcare students. However, this was difficult as their actual work schedules were incompatible with participation in the trial. It should however be further investigated whether having experience with working shifts would have implications regarding replication of the data in the present trial.

The sample had an uneven sex distribution, with 78.5% of the participants being female. This gender distribution is however relatively coherent with epidemiological studies of nurses (approximately 90.0% females), which is a population of shift workers frequently exposed to quick returns (Eldevik et al. 2013; Flo et al. 2014).

Another limitation could be the somewhat uneven balancing in the order of exposure to the conditions, with the final analyses having 60.3% of the participants starting with the QR condition. This could have been partly prevented if the participants had been randomised to the order of the two conditions. Randomisation was however difficult as the mandatory attendance was primarily during daytime and collided with the participants' daily schedules. Regardless, the nights compared in the conditions were at least three days into the trial and it is assumed that the 'first night effect' dissipates after one night of sleep when sleeping with polysomnography (Agnew, Webb, and Williams 1966). As the sleep radar is even less invasive, it is likely that participants were used to the context of having their sleep monitored.

The sleep radar does not measure sleep stages based on physiological parameters such as polysomnography. Instead, the radar is a proxy, as it is based on movement recordings. Compared to polysomnography, however, the radar has been found to be accurate (Pallesen et al. 2018; Toften et al. 2020). Admittedly, sleep radar has not been validated in different populations, such as in healthcare workers, nor on populations with sleep problems/curtailed sleep. However, it has been validated on a student population, which is similar to the sample in the present trial (Toften et al. 2020). Future studies should however apply PSG in a QR context to provide an optimal assessment of sleep stages and validate the current QR simulation model. Using PSG will enable power spectrum analyses, which will provide deeper insights into the quality of each sleep stage. This has been investigated recently in a simulated night work design (Pedersen et al. 2022). Future studies should also measure sleep stages in field studies of QRs. This will allow for further scrutiny of the ecological validity of our findings. This is however the first study simulating QRs in a controlled laboratory context, showing that shortened time off shifts has an effect on common sleep parameters, in addition to indicating effects on sleep architecture.

Lastly, it remains unknown how work performance is affected by QRs, and further studies should conduct performance measurements associated with this shift work characteristic. Performance measurements could emphasise cognitive aspects of performance, such as tests related to REM dependent tasks like emotional (Schäfer et al. 2020), procedural and implicit memory (Rasch and Born 2013). Such performance data may provide insights into specific work tasks that may contribute to an increased risk of occupational accidents in relation to QRs (Nielsen et al. 2019; Vedaa et al. 2019; Vedaa et al. 2020).

5. Conclusion

Our findings showed that the laboratory QR model shortened TST by approximately one hour, compared

to the DD condition, corroborating the findings from field studies of QRs and demonstrating a causal effect of short time off between shifts on sleep. This also validates the QR model and provides a basis for an ecologically oriented design for studying QRs. The findings further suggest that sleep during QRs is of subjectively reported worse quality and may consist of less light-, deep- and REM sleep. Lastly, the findings did not indicate higher pre-sleep arousal between conditions as measured with the PSAS. This could suggest that short time off between shifts alone may be insufficient to increase pre-sleep arousal. The findings regarding the sleep stages and pre-sleep arousal should however be replicated by using other methods of measurement.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data will be provided upon reasonable request to the corresponding author.

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