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Exploring light exposure of hospital nurses working rapidly rotating shifts in relation to sleepiness and sleep

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Abstract. Nightshift work can negatively impact sleep, performance, and health. Careful manipulation of light exposure patterns can help reduce these negative effects but is challenging in conditions of rapidly rotating shiftwork and due to individual differences. As chronotype is related to shiftwork tolerance, we explored patterns of sleep, sleepiness, and light exposure during the first day of nightshift work between earlier and later chronotypes, based on data from an observational field study among rapidly rotating hospital nurses. Due to the limited sample size, only descriptive analyses and visual inspection were conducted. In line with findings of lower shiftwork tolerance, earlier chronotypes (N=6) seemed to be sleepier during work and sleep less than later types (N=7). Differences were also observed in light exposure patterns, revealing potential for light exposure interventions, and suggesting a contribution to shiftwork tolerance. For future intervention studies in aiming to identify a light exposure strategy, our findings highlight the importance of investigating light exposure relative to the individual circadian phase.

1. Introduction

Working nightshifts impacts the lives, health, and performance of people [1]. Properly dosed light exposure patterns, could help the adaptation to nightshift work, reduce the sleepiness during and after night work, and help maintain a solid sleep, which is essential for a healthy recovery [2]. Specifically, light may be relevant in several ways: First, dependent on intensity, duration and timing, light can **phase shift** the circadian clock [3], therefore careful manipulation of light exposure may be used to adapt workers to the nightshift. Second, light can have acute effects on **sleepiness** [4,5], thus properly administered light may counteract sleepiness during the nightshift. Third, prior light exposure history can influence the **sensitivity** to circadian and acute effects of light [6], therefore the daily light dose should be considered for interventions using light exposure.

However, adaptation strategies can be particularly challenging in conditions of rapidly rotating shiftwork, where a large variety of consecutive shifts and shift types within and between workers is observed. In addition, personal factors such as age, chronotype, sleep flexibility, personality and gender strongly influence workers' tolerance to shiftwork [7]. In particular, sleep-related shiftwork tolerance has been associated with young age, late chronotype and high sleep flexibility [7]. It is therefore important to consider personal factors when studying light exposure in shiftworkers or for planning light-interventions.

In this paper we present exploratory analyses of a subset of data collected in an observational field study with the aim to identify patterns of light exposure, sleep, and sleepiness, during a nightshift period in rapidly rotating hospital nurses. Specifically, we explored differences in these patterns between chronotypes during the first nightshift in a series of consecutive nightshifts, since the first nightshift may reveal and explain differences in shiftwork tolerance between earlier and later chronotypes due to work performed under high sleep pressure.

2. Methodology

2.1. Study design

An observational field study was conducted among nurses in a hospital in the Netherlands between May–August 2018. Participants were studied over an entire nightshift period. Nightshifts were 8h-shifts starting between 23:00h – 00:00h and ending between 07:00h – 08:00h the next morning. Here we only report results of the first nightshift, which was defined as the period starting from waking up on the day of the first nightshift until waking up from sleep after the first nightshift (~36 hours).

2.2. Participants

In total, 18 female hospital nurses (Mean age 33.6 ± 9.1 years) participated in this study after giving their informed consent. The Munich Chronotype Questionnaire for Shiftwork (MCTQ-Shift)[8] was administered to calculate chronotype as mid-sleep on free days after evening shifts (MSF^E). The MSF^E could only be determined for 13 participants, who were retained for analyses. By means of a median split on MSF^E (Median 04:37h) groups of earlier chronotypes (N = 6, Mean age 35.2 ± 9.54 years, Mean MSF^E = 03:21 ± 01:12h) and later chronotypes (N = 7, Mean age 31.6 ± 9.22, Mean MSF^E = 05:15 ± 00:40h) were determined.

2.3. Measurements and procedure

2.3.1 Sleep parameters, subjective sleep quality, and subjective sleepiness

Objective sleep parameters, subjective measures of sleep quality and daytime sleepiness were collected with the PRO-Diary (CamNtech Ltd, Papworth Everard, UK), a small wearable actigraphy and experience sampling device. The PRO-Diary was worn on the upper arm during the work period and at the wrist during all other times. Sleep parameters were calculated from actigraphy measurements based on sleep times indicated in a diary filled in after every major sleep episode. The diary also included an assessment of subjective sleep quality with the Groningen Sleep Quality Scale (GSQS) [9], which assesses sleep quality on a 14-item scale, with scores ranging from 0–13 and scores ≥6 indicating disturbed sleep. Subjective sleepiness was assessed with the Karolinska Sleepiness Scale (KSS) [10] by a prompt on the PRO-Diary every hour during the wake-period. The KSS measures sleepiness on a 9-point Likert scale ranging from 1 (extremely alert) to 9 (very sleepy, fighting sleep).

2.3.2 Light exposure

Personal light exposure (illuminance and irradiance in 5 different bandwidths) was continuously measured during the entire study period with a light-dosimetry device (Lightwatcher, Object-Tracker, Perchtoldsdorf, AT). Light exposure was recorded every 20sec and subsequently averaged into 1-min epochs. During the day the device was worn at the chest (with sensors facing upward due to the device geometry) and during sleep the device was placed at the bedside. Illuminance measurements of each device were calibrated against an industry standard photometer under simulated daylight conditions according to the setup and procedure as described in [11].

2.4. Data analyses
We compared light exposure, subjective sleepiness and sleep related measurements during the first nightshift day between earlier and later chronotypes. Light exposure was only analysed for photopic illuminance, since this paper focusses on the comparison of light exposure patterns between chronotypes, and the measurements of the irradiance sensors closely followed the illuminance measurements. Individual illuminance profiles were smoothed using a centred moving average with a 5min window. Additionally, individual light exposure dose profiles were calculated from the unsmoothed data using an exponential moving average (EMA) with a decay half-life of 90mins as suggested by Price [12]. The smoothed illuminance and EMA dose data were log-transformed (log10(x+1)) and averaged across chronotypes for each minute relative to clock time (illuminance data) or relative to the time from MSF^E (EMA dose data). Approximate advance and delay regions were adapted from a phase response curve to 1h of bright light [13] based on dim light melatonin onset (DLMO, an indicator of circadian phase) estimated as MSF^E–6h [14]. Furthermore, to characterize timing and duration characteristics, the first clock time after waking up above threshold and the duration of time spent above threshold were calculated for a range of illuminance thresholds between 10lx and 10000lx.

Given the exploratory nature of this study, analyses were limited to visual inspection and descriptive analyses. Note that the very small sample sizes per group made it impossible to perform meaningful statistical analyses of the data.

3. Results

3.1. Sleep-wake times
The first nightshift day started earlier for earlier chronotypes, who woke up on average at 08:05h, as compared to late types, who woke up at 10:22h. Since both types went to bed at the same time after the nightshift (08:49 vs. 08:46), earlier types were on average 2.3h longer awake than later types on the first nightshift day.

3.2. Light exposure
Figure 1(A) shows mean log illuminance across the wake and sleep period on the first nightshift day for earlier and later chronotypes. Interestingly, during the period before work, later chronotypes had a pattern of light exposure with a wide peak of bright light centred around 12:00h, whereas earlier types had two peaks around 11:00h and 18:00h. As a result, later types experienced lower illuminance levels in the evening before the start of the nightshift, which is also highlighted by the offset between the dose profiles for both types. Note that this is not a result of different daylengths from sunrise to sunset, which was similar for earlier and later chronotypes (16.52 ± 0.12h vs. 16.49 ± 0.34h). Interestingly, during the nightshift period, earlier types were exposed to slightly lower illuminance levels towards the end of the shift compared to later types.

Since phase shifting depends on the timing of light relative to circadian phase, we examined light exposure relative to each participant's MSF^E, shown in Figure 1(B) for mean log EMA dose. On this relative scale a large offset between the light exposure profiles of earlier and later chronotypes can be observed, with a substantially higher light dose in the delay regions of an approximate phase response curve dose for earlier compared to later types.

The differences in light exposure characteristics are further highlighted in Figure 1(C) which shows the first clock time after waking up where the light exposure was above a certain threshold. Specifically, the earlier wake-timing of earlier chronotypes is reflected in earlier exposure to light above 10lx for earlier compared to later types. Furthermore, a tendency can be seen for the timing profiles to meet above a threshold of ~500lx, suggesting that on average earlier types receive bright light at a similar time as later types despite waking up earlier. This tendency is in line with similar durations spent under bright light conditions as can be seen in Figure 1(D). Interesting to note here is the distinct change in slope around 200-500lx, corresponding to the transition between typical indoor and outdoor lighting conditions, suggesting that most time was spent indoors. When considering >1000lx as typical bright daylight conditions, participants spent on average 3.2 hours in daylight (later types 2.85h, earlier 3.5h).

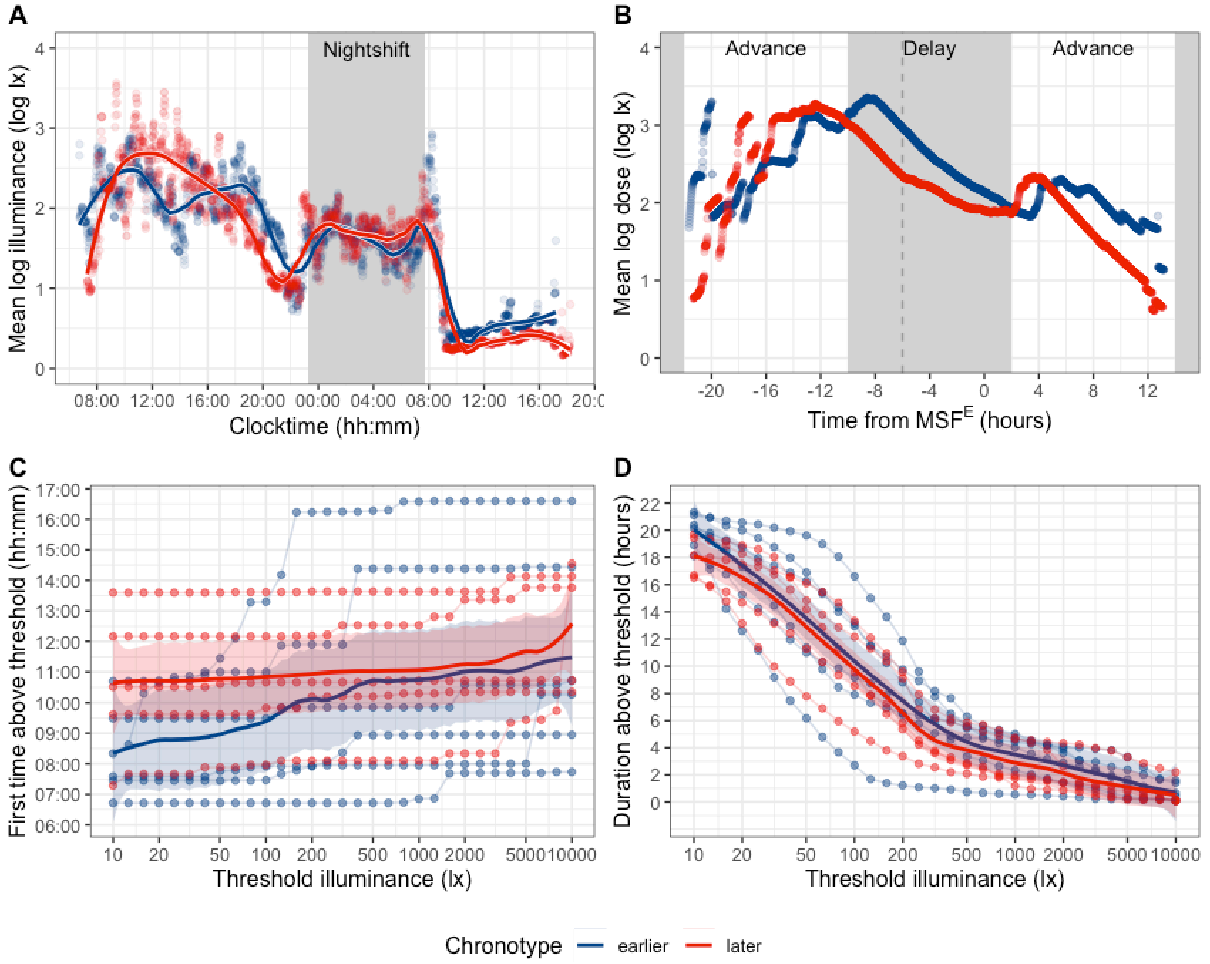

Figure 1. Light exposure characteristics during the first nightshift day, for earlier and later chronotypes: **A)** mean log illuminance relative to clocktime, **B)** mean log EMA dose relative to MSF^E (mid-sleep on free days after evening shifts, an estimate of chronotype), with dashed line indicating DLMO estimated as MSF^E–6h [14] and approximate delay and advance regions adapted from the phase response curve of [13], **C)** first clocktime above illuminance threshold, and **D)** duration of time above illuminance threshold. Smoothed lines show local regression curves (LOESS; span = 0.2) with standard error.

3.3. Subjective Sleepiness

Figure 3(A) shows KSS score as a function of clocktime across the first nightshift day for earlier and later chronotypes. During the period before work, KSS scores remained relatively low and were similar for earlier and later chronotypes (3.66 ± 0.75 vs. 3.25 ± 1.17). Throughout the nightshift, KSS scores increased, with higher scores (i.e., sleepier) on average for earlier chronotypes compared to later chronotypes (4.99 ± 1.30 vs. 3.44 ± 1.19) and persisted after the nightshift until going to bed. When examining KSS score as a function of time awake (Figure 3(B)), some of the observed difference in nocturnal KSS scores may be explained by longer times awake with earlier chronotypes on average waking up earlier than later types (08:05h vs. 10:22h) before the first nightshift day.

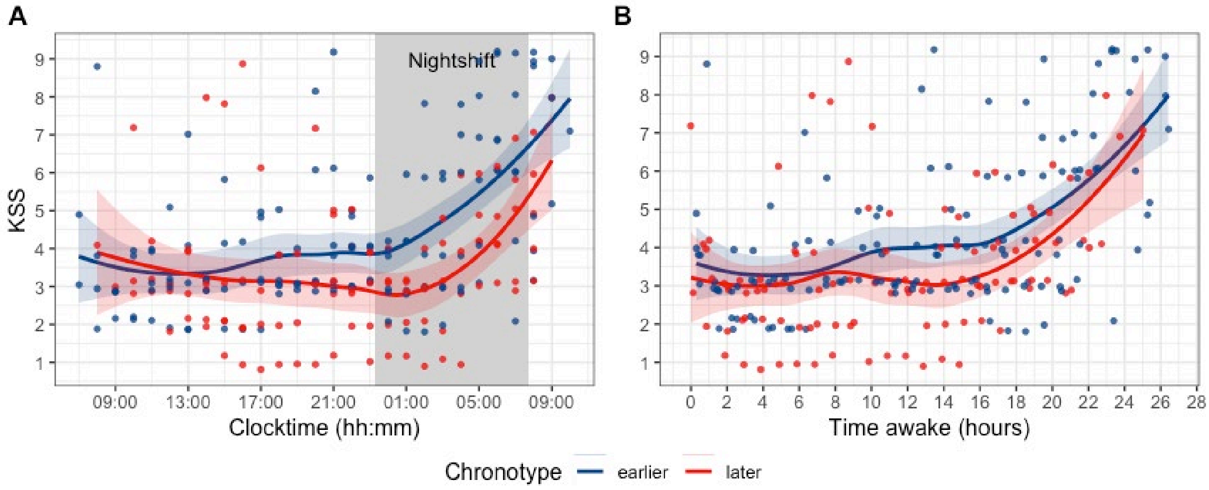

Figure 2. KSS score during the wake-period on the first nightshift day, per participant, for earlier and later chronotypes: **A)** relative to clocktime, and **B)** relative to time awake. Smoothed lines show local regression curves (LOESS; span = 0.2) with standard error. Data points are displayed jittered for readability.

3.4. Sleep
Overall, sleep after the first nightshift compared to the day before was shorter (6.60 ± 2.19h vs. 7.53 ± 2.08h) and more fragmented (Fragmentation Index = 28.6 ± 16.0 vs. 22.7 ± 12.5). Moreover, GSQS scores were higher for sleep after the first nightshift than the day before (8.00 ± 3.04 vs. 5.14 ± 4.63, with scores above 6 indicating disturbed sleep). When comparing chronotypes, only limited data were available for the first nightshift day (earlier N=4, later N=5) due to missing data. However, there was a tendency for earlier compared to later types to sleep less (5.68 ± 2.46h vs. 7.34 ± 1.87h) and have more fragmented sleep (38 ± 13.06 vs. 21 ± 14.98) after the first nightshift.

4. Discussion & Conclusions
The exploratory results presented here are in line with findings of previous studies, suggesting that later chronotypes have a higher tolerance towards working nightshifts compared to earlier types [7], at least for the first day of a nightshift period. Specifically, later types seemed to be less sleepy during the first nightshift and seemed to sleep longer and have less fragmented sleep compared to earlier types. Two main factors that may underly these patterns are different circadian timing and homeostatic sleep-pressure during the nightshift for both chronotypes. That is, due to their later circadian phase, later chronotypes were already more adapted to nightshift work and performed work during a slightly more "normal" circadian time, while simultaneously, sleep pressure was lower during the shift, due to later wake-up times and therefore less time awake.

The different wake-up times also shaped the light exposure patterns of both chronotypes, with later types receiving more bright light after awakening due to waking up towards noon, while earlier types woke up earlier but tended to spend the morning at lower light levels. While light exposure during the nightshift seemed similar, when examining the light exposure profiles relative to internal circadian phase (estimated as MSF^E) a substantial offset can be observed between chronotypes. That is, earlier types had a much higher light dose during the approximate phase delay region than later types. Interestingly, in theory based on the observed light pattern, better adaptation for earlier types may be expected compared to later types. However, the phase delaying effects of in earlier types could have counteracted by the higher light dose in the phase advance region after the nightshift, preventing adaptation. Unfortunately, the limited sample size and large variation in the number of shifts work of the dataset did not allow for similar analyses of subsequent nightshifts. Nevertheless, these findings highlight the importance of investigating light exposure relative to circadian phase, given the strong association between relative light exposure and diurnal preference with adaptation to nightshift work [15]. Moreover, since prior light history has been shown to modulate circadian and acute effects [6], exposure dose should be taken into account for future studies. Here we used a method suggested by Price [12] to quantify accumulated light exposure dose with an exponential moving average. Given the simplicity of this method, further research into its validity for quantifying light exposure dose and non-visual effects is warranted. Particularly interesting would be to investigate whether observed reductions in sleepiness during the nightshift may be partly explained by a lower light exposure dose at the start of the shift, increasing sensitivity to light during the night.

In conclusion, our findings are in line with findings suggesting greater shiftwork tolerance for later chronotypes than for earlier types. The observed light exposure patterns were different for both chronotypes which might have impacted these findings, and potentially the adaptation throughout the entire nightshift period. For future intervention studies, our findings highlight the importance of investigating light exposure relative to circadian phase. Especially earlier chronotypes may profit from targeted light interventions to improve sleep and sleepiness during nightshift.

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