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Original Article

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Diet, Physical Activity, and Daylight Exposure Patterns in Night-Shift Workers and Day Workers

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Abstract

Background: Night-shift work has been reported to have an impact on nutrition, daylight exposure, and physical activity, which might play a role in observed health effects. Because these exposures show diurnal variation, and shift work has been related with disturbances in the circadian rhythm, the timing of assessment of these factors requires careful consideration. Our aim was to describe the changes in patterns of diet, physical activity, and daylight exposure associated with night-shift work.

Methods: We conducted an observational study among female healthcare workers either regularly working night shifts or not working night shifts. We assessed physical activity and daylight exposure using continuous monitoring devices for 48 h. We logged dietary patterns (24 h) and other health- and work-associated characteristics. Two measurement sessions were conducted when participants did 'not' work night shifts, and one session was conducted during a night-shift period.

Results: Our study included 69 night-shift workers and 21 day workers. On days in which they conduct work but no night work, night-shift workers had similar physical activity and 24-h caloric intake, yet higher overall daylight exposures than day workers and were more often exposed around noon instead of mainly around 1800h. Night-shift workers were less exposed to daylight during the night-shift session compared to the non-night-shift session. Total caloric intakes did not significantly differ between sessions, but we did observe a shorter maximum fasting interval, more eating moments, and a higher percentage of fat intake during the night-shift session.

Conclusion: Observed differences in diet, physical activity, and exposure to daylight primarily manifested themselves through changes in exposure patterns, highlighting the importance of time-resolved measurements in night-shift-work research. Patterns in daylight exposure were primarily related to time of waking up and working schedule, whereas timing of dinner seemed primarily governed by social conventions.

Keywords: chronobiology; circadian rhythm; daylight exposure; dietary pattern; exposure assessment; night work; occupational health; physical activity; shift work

Introduction

Night-shift work has become an unavoidable part of our industrial society. In developed countries, ~15–20% of the working population is working in shifts partially or completely outside daytime working hours (0600–1800h) (IARC Working Group, 2007; McMenamin, 2007). In the last decades, many large cohort studies have provided evidence for the potential impact of shift work on health-related outcomes, particularly those connected to perturbations of the circadian rhythm (Megdal et al., 2005; IARC Working Group, 2007; Antunes et al., 2010; Puttonen et al., 2012; Canuto et al., 2013; Kamdar et al., 2013). Shift work, especially night-shift work, has been reported to cause changes in a range of lifestyle factors and environmental exposures. Three factors that have been described more extensively in the literature include changes in nutrition (Rüger and Scheer, 2009; Antunes et al., 2010), altered daylight exposure (Fritschi et al., 2011), and changes in physical activity (Bøggild and Knutsson, 1999; Frost et al., 2009; Nabe-Nielsen et al., 2011; Vyas et al., 2012). As both night-shift work and its potentially related health outcomes are closely connected to the circadian rhythm and associated diurnal variation, the timing of the assessment of these factors requires careful consideration.

Although night-shift work has been reported to not affect total caloric intake over 24 h (Esquirol et al., 2009; Puttonen et al., 2010), it has been reported to affect the timing of eating (more during the night), energy distribution of meals [smaller portions (Antunes et al., 2010); more high-fat snacks (Antunes et al., 2010)], and the frequency of eating moments (including the impact on the hours of non-eating, i.e. fasting) (Stokkan et al., 2001). These more detailed dietary measures are important to assess because of the impact on metabolic factors such as glucose tolerance and energy metabolism.

Working in shifts has also been reported to affect the time spent outside during daytime and, therefore, the total amount of daylight exposure received and its positive impact on health (Fritschi et al., 2011; Hansen and Lassen, 2012). Daylight is an important 'zeitgeber' and altered patterns in daylight exposure (e.g. exposure to daylight during sleep) have been reported to affect normal diurnal rhythm (Fritschi et al., 2011). To study the impact of shift work on exposure to daylight, a focus on both absolute amounts of daylight and timing of daylight is relevant. Finally, night-shift work has been associated with a total decrease in physical activity (Bøggild and Knutsson, 1999). Similar to diet and exposure to daylight, it is likely that night-shift work, in addition to an impact on total physical activity, has an impact on the times of day at which shift workers are active. An important research question is, therefore, how patterns in physical activity change due to night-shift work, which might have a potential impact on the role of physical activity as zeitgeber (Yamanaka et al., 2006). For all three exposure factors, i.e. physical activity, light, and diet, both aggregated data variation and pattern changes are relevant.

Owing to their shared determinant (i.e. night-shift work), correlations in exposure patterns between nutrition, exposure to daylight, and physical activity are expected. This makes it difficult to assess a potential independent effect of each of these determinants on human health. We considered it, therefore, relevant to assess the degree to which exposure patterns are correlated and to identify factors that have an impact on this correlation.

We conducted a panel study among women regularly working in night shifts and a comparable group of women not working night shifts. We applied state-of-the-art monitoring methods to assess patterns of three exposure factors (diet, daylight, and physical activity). We assessed exposure patterns among night-shift workers and day workers for 48 h during which they were working but not working night shifts. Among night-shift workers, we also assessed a 48-h period during a night shift.

Methods

Recruitment study population

We recruited female healthcare workers aged 18–67 years that either worked in a schedule including night shifts at least once every 6 weeks (night-shift workers) or had not worked in night shifts the last 5 years before recruitment (day workers). 'Night shift' was defined as work that covers ≥1 h between midnight and 0600h. 'Day work' was defined as all work that does not cover the definition of a 'night shift', and apart from traditional working hours during the day, this also included morning and afternoon shifts. Time intervals between the work shifts and the direction of rotation of the work shifts are not fixed and varied from person to person. Hospitals included in our study worked with a schedule that is made in consultation with the nurses and based on personal preferences.

To participate in the study, subjects had to agree to blood sampling (results not included in this article), fill out the questionnaires, and wear sensors. We excluded current smokers and former smokers who quit smoking <6 months before study inclusion [<100 cigarettes during lifetime were considered nonsmokers (Centers for Disease Control and Prevention (CDC) 2011)]. We excluded participants that were pregnant (or had been in the six months before inclusion); were undergoing fertility treatment; had ever been diagnosed with cancer (excluding nonmelanoma skin cancer), high blood pressure (using beta-blockers), and cardiovascular disease; and used melatonin supplementation or medication for chronic disorders including diabetes We approached potentially eligible participants in five hospitals in the Dutch cities Amsterdam and Utrecht via their employer. All participants signed an informed consent. Inclusion of the participants took place between February 2015 and February 2017. The study was approved by the medical ethics committee of the UMCU Hospital in Utrecht, the Netherlands (14-611D, NL51501.041.14).

Study design

The design of our study is graphically presented in Appendix I in Supplementary data (available at *Annals of Work Exposures and Health* online). Our study consisted of monitoring sessions during which study participants were followed for 48 h. For night-shift workers, we conducted monitoring sessions at two times during their shift-work cycle: (i) during the last 48 h of a series of night shifts [night-shift session (consisting of two consecutive night shifts, i.e. working between midnight and 0600h for ≥1 hour)], and (ii) during the last 48 h of a series of non-night shifts, being either morning or evening shifts. Non-night-shift sessions (consisting of two consecutive non-night shifts) were followed twice and night-shift sessions once.

General lifestyle questionnaire, 48-h log, and body mass index

Participant characteristics were acquired by questionnaires and included age, education, marital status, shift work experience, and chronotype. Chronotype was based on an item of the scale of Horne and Ostberg (1976) on diurnal preference with five categories (obvious morning preference, more morning than evening preference, more evening than morning preference, obvious evening preference, and no specific type). Participants kept a 48-h log of lifestyle parameters, including alcohol consumption, caffeine intake, sleep quality, (shift-) work schedule, mode of transportation, and physical activity. Weight and height were measured and body mass index (BMI) was calculated (weight in kilograms divided by height in meters squared).

Exposure assessment

Assessment of nutrition

During the last 24 h of a 48-h session, participants logged dietary patterns. We asked study participants to specify their diet (timing, product, and quantity). Using these dietary logs, we calculated total energy intake and macronutrients using a Dutch nutrient database (NEVO, 2016), the number of meals per 24 h that generated a calorie intake higher than 5 kcal, and the maximum consecutive number of hours in between meals over the 24-h period (maximum fasting intensity).

Assessment of physical activity

Participants wore a physical activity sensor for 48 h for each session (ActiGraph GT3X accelerometer, Pensacola, FL, USA) on their right hip during the period they were awake (and on their right wrist while sleeping). Raw accelerometer data were converted into ENMO (Euclidean norm minus 1 g) scores (van Hees et al., 2013), which were used to calculate 24-h mean activity (ENMO, mg) and estimates of moderate-to-vigorous physical activity (MVPA, reflecting 3–6 metabolic equivalents) using the GGIR package for R (van Hees et al., 2013).

Assessment of exposure to daylight

Lighting conditions were measured for 48 h per session using the HOBO Pendant Temperature/Light Data Logger UA-002-64 (Onset Computer, Bourne, MA, USA) (Martinez-Nicolas et al., 2011; Bonmati-Carrion et al., 2014). All participants were required to wear the light sensor on their chest over their upper layer of clothing, with the light sensor facing outward. During sleep they were instructed to leave the sensor on the bedside table, also with the sensor facing outward. Light intensity (range between 0 and 320 000 lux) was measured every 10 s. We classified exposure to dim and full daylight as percentage of time, respectively, >500 and >1000 lux, and exposure to sunlight as percentage of time >10 000 lux (Dharani et al., 2012).

Statistical analyses

Monitoring data were analyzed both as (24 or 48 h) total aggregates and time-resolved quantities/exposure patterns. Analyses were conducted to compare measurements between day workers and night-shift workers (during a non-night-shift period). Among night-shift workers, we compared collected measurements between a night-shift session and a non-night-shift session.

Aggregated data

We generated Spearman correlation matrices incorporating estimates for nutrition, physical activity, and exposure to daylight to assess correlation patterns between these factors. To accommodate our repeated measurement structure, we estimated contrasts using a linear mixed-effects regression model [LMER package for R (Bates et al., 2015)]. We considered a contrast with an associated *P* value of <0.05 as statistically significant. Skewed data (light exposure and physical activity) were log-transformed. All regression models were adjusted for potential confounding factors: BMI, education level (a medium level of education was defined as having a degree in applied sciences and a high level of education was defined as having an academic degree), chronotype, and daylight saving time [summertime versus wintertime (McLaughlin et al., 2008)]. We stratified data by BMI [obese (BMI ≥ 25 kg m^{-2}) versus nonobese participants (BMI < 25 kg m^{-2})] and by daylight saving time, and tested for statistical significance of these potential effect modifiers.

Time-resolved exposure patterns

We plotted patterns of exposure to daylight in lux with a resolution of 10 s, physical activity in ENMO per minute, and average caloric intake per hour, both on actual clock time and time relative to wake-up time (zero is wake time) of participants over a range of 24 h. For exposure to daylight and physical activity, all data from a 48-h monitoring session were combined regardless of the date of sampling. Similarly, data from the two non-night-shift monitoring sessions were combined as well. We created bar plots representing per hour the percentage of the study population that was at work and percentage that was sleeping, using self-reported information. To facilitate interpretation of the time-resolved exposure patterns, we manually indicated midpoints (or modes) of major peaks with a vertical line.

We assessed the robustness of our assessment of patterns in exposure to daylight and physical activity by splitting data from the 48-h monitoring sessions in separate 24-h sessions and comparing the similarity in observed time-resolved patterns. For nutrition (for which we only had 24-h data available), we assessed the similarity in time-resolved patterns between the two non-night-shift monitoring sessions.

Results

General characteristics

At time of recruitment, 69 participants reported to regularly work in night shifts and 21 participants reported that they had not worked in night shifts in the 5 years before recruitment. Night-shift workers were somewhat younger than day workers (45 versus 49 years), higher educated (72% versus 65%), more often an evening chronotype (37% versus 20%), and had a similar BMI (26.6 versus 26.9 kg m^{-2}), as shown in Table 1. On average, night-shift workers worked five night shifts per month (3 SD) and three consecutive night shifts (1 SD).

Comparison between night-shift workers and day workers during a non-night-shift session

Aggregated data

We observed no significant difference between night-shift workers and day workers in total energy intake during sessions that did not contain night shifts (Table 2). We observed a significant (*P* = 0.046) higher carbohydrate intake (4%; CI: 0.1% to 7.8%) and trend toward lower fat intake (−3.6%; CI: −7.7% to 0.4%) for night-shift workers compared to day workers. Sensitivity analyses indicated that these results were mainly driven by obese participants (Supplementary Table 1a of Appendix III in Supplementary data, available at *Annals of Work Exposures and Health* online). We observed a significant interaction of night work with BMI for fat intake (*P* = 0.033) and a *P* value of 0.126 for carbohydrate intake (data not shown). The higher carbohydrate intake and lower fat intake for night-shift workers were mainly observed during wintertime (Supplementary Table 2a of Appendix IV in Supplementary data, available at *Annals of Work Exposures and Health* online), although this was not statistically significantly different from summertime (*P* = 0.554 for carbohydrate intake and *P* = 0.314 for fat intake). The largest interval between eating episodes was 2.6 h longer for night-shift workers (CI: 1.2% to 4.1%) and the frequency of meals was one eating moment less compared to day workers (*P* = 0.08). Although we observed no significant difference in ‘measured’ physical activity between night-shift workers and day workers, ‘self-reported’ physical activity was 97% higher (CI: 7% to 263%) in night-shift workers (Table 2). Among the nonobese, night-shift workers had 50% less time above the MVPA threshold (CI: –75% to –1%) compared to day workers (*P* = 0.055). In the obese subset, night-shift workers tended to have 28% more time above the MVPA threshold compared to day workers (*P* = 0.321) (Supplementary Table 1a of Appendix III in Supplementary data, available at *Annals of Work Exposures and Health* online). This difference between obese and nonobese workers on MVPA was significant (*P* value of effect modification of obesity 0.017).

Night-shift workers had longer exposures to daylight than day workers (Table 2), with an increasing threshold for light intensity: night-shift workers received 51% more time > 500 lux, 146% more time > 1000 lux (full daylight), and 302% more time > 10 000 lux (sunlight). This pattern of longer light exposures was corroborated

Table 1. General characteristics: night-shift workers compared to day workers.

	Night-shift workers (*n* = 69)	Day workers (*n* = 21)
Age in years (mean ± SD)	45 ± 12	49 ± 11
Educational level[a] in % (at least bachelor degree)	72	65
Marital status in % (married/cohabiting)	69	65
Chronotype[b] in % (evening type)	37	20
Number of hours worked per week (mean ± SD)	31 ± 6	30 ± 5
Body mass index[c] (mean ± SD)	26.6 ± 5.2	26.9 ± 5.5
Waist circumference in cm (mean[d] ± SD)	84 ± 12	87 ± 10
Total caloric intake in kcal (mean[d]/24 h ± SD)	1876 ± 521	1820 ± 424
Alcohol consumptions (mean[d]/24 h ± SD)	0.5 ± 0.8	0.3 ± 0.4
Coffee consumptions (mean[d]/24 h ± SD)	2.7 ± 1.9	3.4 ± 1.9
Physical activity MVPA (mean[d] min/24 h ± SD)	40.1 ± 35.2	38.2 ± 26.8
Self-reported physical activity (mean[d] min/24 h ± SD)	105 ± 197	63 ± 125
Daylight exposure (mean[d] min >500 lux 48 h ± SD)	174 ± 151	216 ± 199

[a] Percentage with bachelor degree (applied sciences) or academic degree (master level).
[b] Percentage with answer categories 'more evening than morning preference' and 'obvious evening preference'.
[c] Weight in kilograms divided by height in meters squared.
[d] Weighted average over two non-night-shift sessions (if available, otherwise based on one session).

Table 2. Night-shift workers (*n* = 69) compared to day workers (*n* = 21) during a non-night-shift session.

	Estimate[a] (SE)	lcl, ucl 95%	*P* value*
Total caloric intake (mean/24 h)	–114 (143)	–394, 166	0.425
Proteins (% of total energy 24 h)	–0.2 (0.1)	–2.1, 1.8	0.879
Carbohydrates (% of total energy 24 h)	4.0 (2.0)	0.1, 7.8	**0.046**
Fats (% of total energy 24 h)	–3.6 (2.1)	–7.7, 0.4	0.082
Saturated fats (% of total energy 24 h)	–1.2 (0.9)	–3.0, 0.6	0.207
Fibers (g over 24 h)	0.4 (2.4)	–4.3, 5.2	0.856
Maximum fasting intensity (hours over 24 h)	2.6 (0.7)	1.2, 4.1	**0.001**
Frequency (no. of meals >5 kcal over 24 h)	–1.0 (0.6)	–2.1, 0.1	0.080
Physical activity (% of time >MVPA threshold over 24 h)[b]	–5 (20)	–36, 42	0.802
Physical activity (% of self-reported time over 24 h)[b]	97 (30)	7, 263	**0.032**
Daylight exposure (% of time >500 lux over 48 h)[b]	51 (24)	–5, 139	0.083
Daylight exposure (% of time >1000 lux over 48 h)[b]	146 (31)	34, 353	**0.005**
Sunlight exposure (% of time >10 000 lux over 48 h)[b]	302 (44)	68, 858	**0.002**
Time spent outside during daylight (% of self-reported time over 48 h)[b]	31 (20)	–11, 94	0.179

Bold values indicate statistically significant *P* values at <0.05.
[a] Adjusted for age, BMI, education, chronotype, and summer/wintertime.
[b] Log-transformed data.
**P* value is based on mixed effect model (repeated measurements within participant).

by a self-reported 97% longer time period spent outside by night-shift workers compared to day workers.

The correlation pattern (Appendix II in Supplementary data, available at *Annals of Work Exposures and Health* online) was different for day workers compared to night-shift workers (during a non-night-shift session) because only day workers had moderate inverse correlations between total caloric intake and light exposure >1000 lux (–0.58) and moderate positive correlations with percentage of protein intake (*r* = 0.50). Self-reported time spent outside showed a weak positive correlation with measured light outcomes of >1000 lux for day workers (*r* = 0.22), but not for night-shift workers (*r* = 0.02). Only within day workers, light exposure (>1000 lux) was weakly correlated with both measured (*r* = 0.17) and self-reported physical activity (*r* = 0.27). Total caloric intake was negatively correlated (*r* = –0.58) to a moderate degree with daylight exposure (>1000 lux) in day workers. Finally, in day workers, MVPA was negatively correlated (*r* = –0.23) to fat intake.

Time-resolved exposure patterns

Figures 1 and 2 reflect 24-h patterns for total caloric intake, physical activity, and exposure to daylight plotted against wall clock time. Twenty-four-hour patterns in total energy intake of day workers and

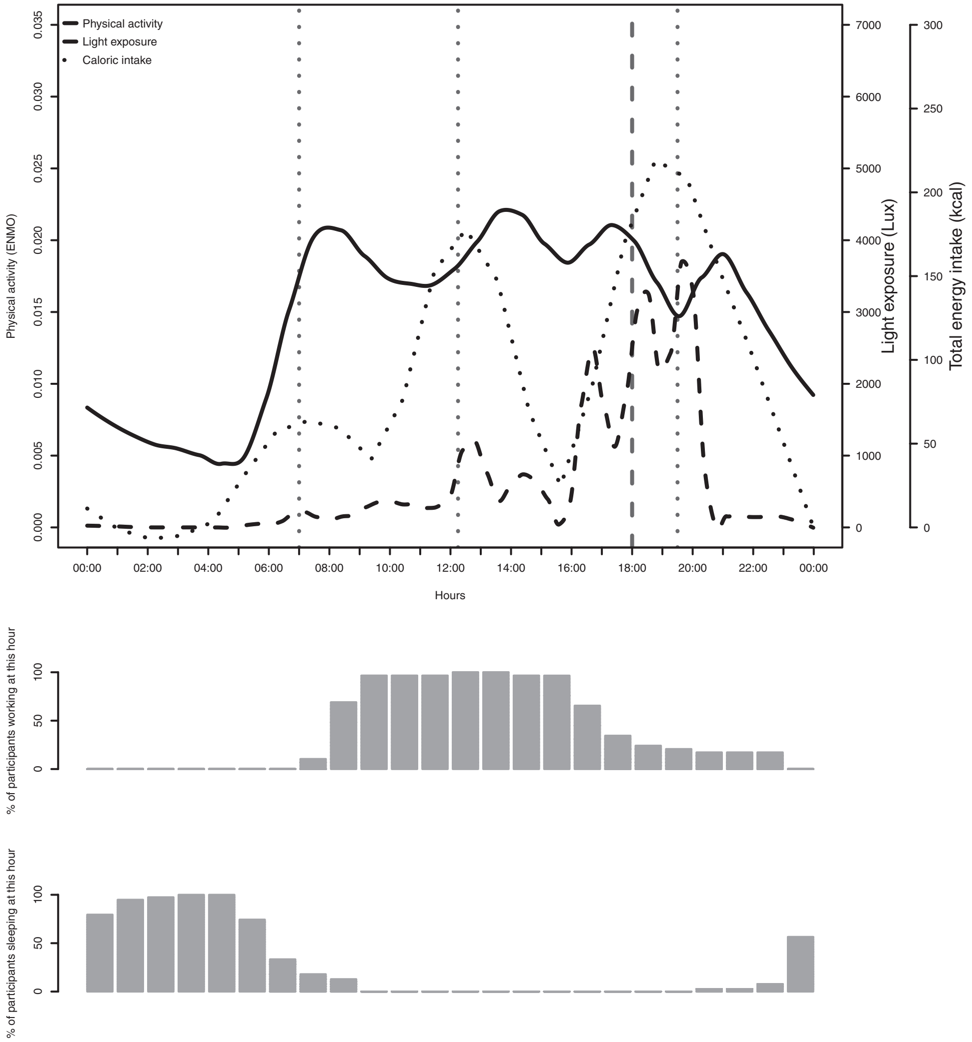

Figure 1. Day workers ($n = 21$) during a non-night-shift session. Pattern of light intensity (lux per 10 s), total energy intake (kcal h^{-1}), and activity pattern (ENMO scores per minute) over 24 h. Bar plots reflect the percentage of participants working at this particular hour and sleeping at this particular hour. The late-hour work segments reflect a subset ($n = 3$) of workers performing evening shifts, whereas the majority ($n = 18$) performed day shifts. Modes were manually added to reflect the midpoint of the peak of an exposure.

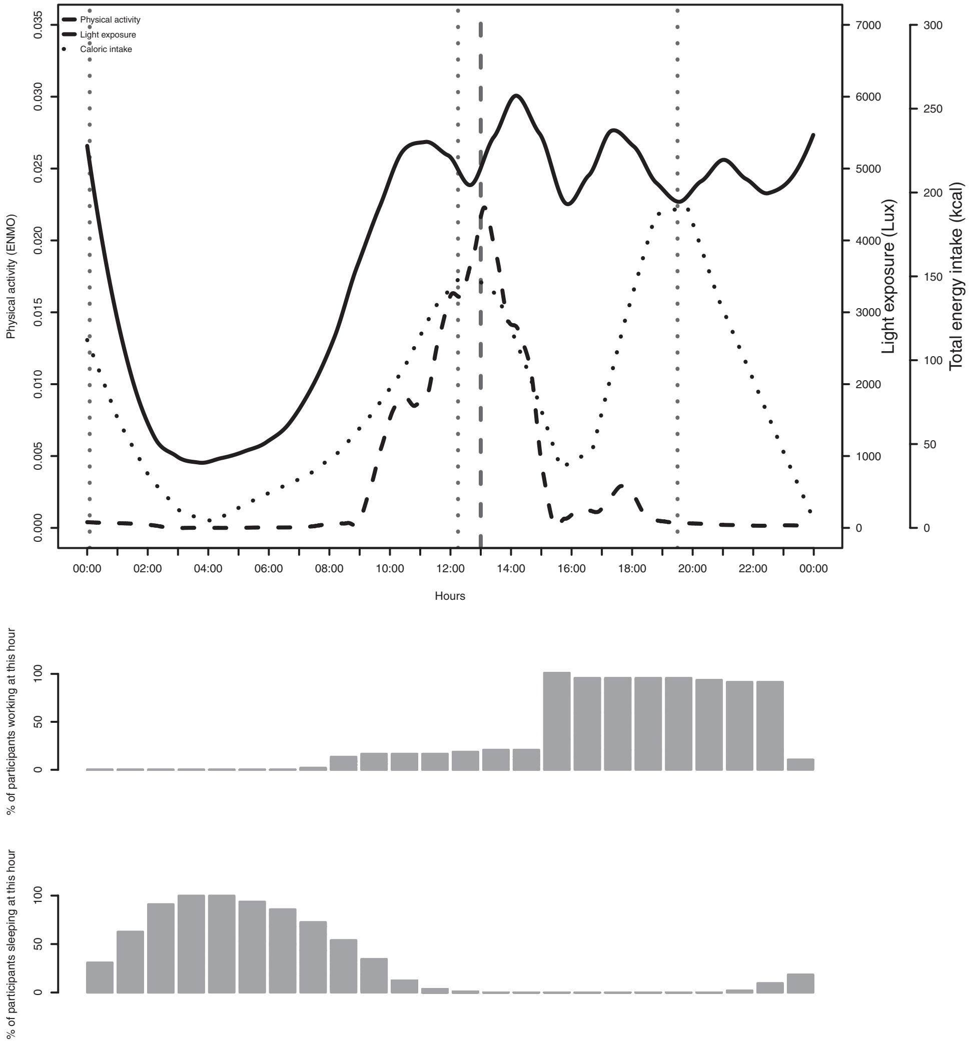

Figure 2. Night-shift workers during non-night-shift session ($n = 69$). Pattern of light intensity (lux per 10 s), total energy intake (kcal h^{-1}), and activity pattern (ENMO scores per minute) over 24 h. Bar plots reflects the percentage of participants working at this particular hour and sleeping at this particular hour. The early-hour work segments reflect a subset ($n = 8$) of workers performing morning shifts, whereas the majority ($n = 61$) performed evening shifts. Modes were manually added to reflect the midpoint of the peak of an exposure.

night-shift workers resembled each other in that both groups showed two distinct peaks (modes at ~1200h and 1930h), corresponding to lunch and dinner times. However, day workers also had a peak at breakfast time (modes around 0700h) and night-shift workers around midnight (mode at 0000h). Day workers became physically active at an earlier time (~0730h) than night-shift workers (around 1000h), which corresponded with later working times. The highest exposure to daylight was received before start of the shift for night-shift workers, and for day workers after the end of their shift.

When plotted against wake-up time, caloric intake peaks for breakfast, lunch, and dinner stayed visible for day workers, whereas for night-shift workers patterns became less pronounced (Supplementary Figure 3a of Appendix V in Supplementary data, available at *Annals of Work Exposures and Health* online), due to a higher variation in wake-up time and relatively fixed dinner times. Patterns of physical activity were similar between night-shift workers and day workers when plotted against wake-up time, with a strong increase in the first 2 h and steady decline 15 h after waking up (Supplementary Figure 3b of Appendix V in Supplementary data, available at *Annals of Work Exposures and Health* online). In addition, we observed more activity in night-shift workers compared to day workers, which was also reported by the participants (97%; CI: 7% to 263%; see Table 2). Night-shift workers were exposed to daylight during a time period of 0000–0600h after waking up, whereas day workers had their peak exposure after ~12 h after waking up (Supplementary Figure 3c of Appendix V in Supplementary data, available at *Annals of Work Exposures and Health* online).

Comparison between night-shift sessions and non-night-shift sessions among night-shift workers

Aggregated data

We observed no significant differences in total caloric intake (122 kcal; CI: –42 to 286 kcal) and a borderline significant 2.3% increase in fat intake (CI: 0.01% to 4.7%) when comparing night-shift sessions to non-night-shift sessions (Table 3) within night-shift workers. During the night-shift session alone, we found a moderate negative correlation between carbohydrate intake and protein intake in percentages ($r = -0.54$; Appendix II in Supplementary data, available at *Annals of Work Exposures and Health* online). During a night-shift session, participants had a significantly shorter 3.7-h maximum interval between eating episodes (CI: –4.7% to –2.6%) and 0.9 higher frequency of meals (CI: 0.3% to 1.5%) compared to a non-night-shift session. When we stratified on obesity (Supplementary Table 1b of Appendix III in Supplementary data, available at *Annals of Work Exposures and Health* online), we saw that only obese participants had a higher fat intake (3.2%, CI: 0.4% to 6.0%), whereas mainly for the nonobese participants, total energy intake was higher (222 kcal; CI: –82 to 526 kcal) during the night-shift session. During wintertime we saw a higher total energy intake of 295 kcal (CI: –24 to 615 kcal), significantly less protein intake of 2.3% (CI: –4.4% to –0.2%), and significantly more fat and saturated fat intake [respectively, 4.8% (CI: 0.8% to 8.8%) and 2% (CI: 0.1% to 3.8%)] during a night-shift session compared to a non-night-shift session. Only during summertime were significant lower levels of MVPA observed (–27% in time above the MVPA threshold, CI: –44% to –4%) during the night-shift session compared to a non-night-shift session (Table 3). Measured (71% decrease in time >1000 lux) and self-reported (60% less time spent outside during daylight hours) light-exposure measures were significantly lower during night-shift sessions compared to non-night-shift sessions.

Time-resolved exposure patterns

During night-shift sessions (Fig. 3), we observed a peak in caloric intake during the night (mode at 0300h) and in the morning at 0900h, but no peak during lunch time, which we did observe during the non-night-shift session (mode at 1215h, Fig. 2). For both sessions, a peak of caloric intake was observed at 1930h (corresponding to dinner time). Physical activity peaked in the morning and evening (modes at 0830h and 2230h, respectively), which corresponded to participants commuting to and from work when working a night shift. Peak exposures in daylight were observed at ~1300h during non-night-shift sessions (Fig. 2) and at ~1000h and 1800h during night-shift sessions (Fig. 3).

Plotted against wake-up time (Supplementary Figure 4 of Appendix V in Supplementary data, available at *Annals of Work Exposures and Health* online), patterns for all exposure metrics during the non-night-shift session decreased over time and had lower exposures during the time period when most participants were sleeping (~1600–2400 h after waking up). However, during the night-shift session, light intensity was higher during the sleep period and there was more activity throughout the whole 24 h, whereas during a non-night-shift session, there was a decrease in activity 1600h after waking up. During the night-shift session, participants had highest caloric intake directly after waking up.

Repeatability of time-resolved patterns

Patterns were generally robust across repeated 24-h measurements, although we observed a shift for light-exposure modes among night-shift workers during the night-shift session (Appendix VI in Supplementary data, available at *Annals of Work Exposures and Health* online).

Discussion

We observed that, on days that they had not conducted night-shift work, night-shift workers differed from day workers in the timing of energy intake and physical activity, but not in average exposures. Night-shift workers had longer exposure to daylight than day workers and were more often exposed around noon instead of mainly around 1800h. During the night-shift session, night-shift workers had less exposure to daylight than during the non-night-shift session, whereas physical activity levels and total caloric intakes were similar. Further, during the night-shift period, the maximum fasting interval was shorter and there were more eating moments.

Comparison between night-shift workers and day workers during non-night-shift sessions

We observed that participants mainly ate at fixed wall clock times regardless of their shift type or wake-up time. This phenomenon was most prominently visible for the time at which the largest meal took place (dinner, around 1930h) and was probably largely due to the influence of social conventions (cultural norms and

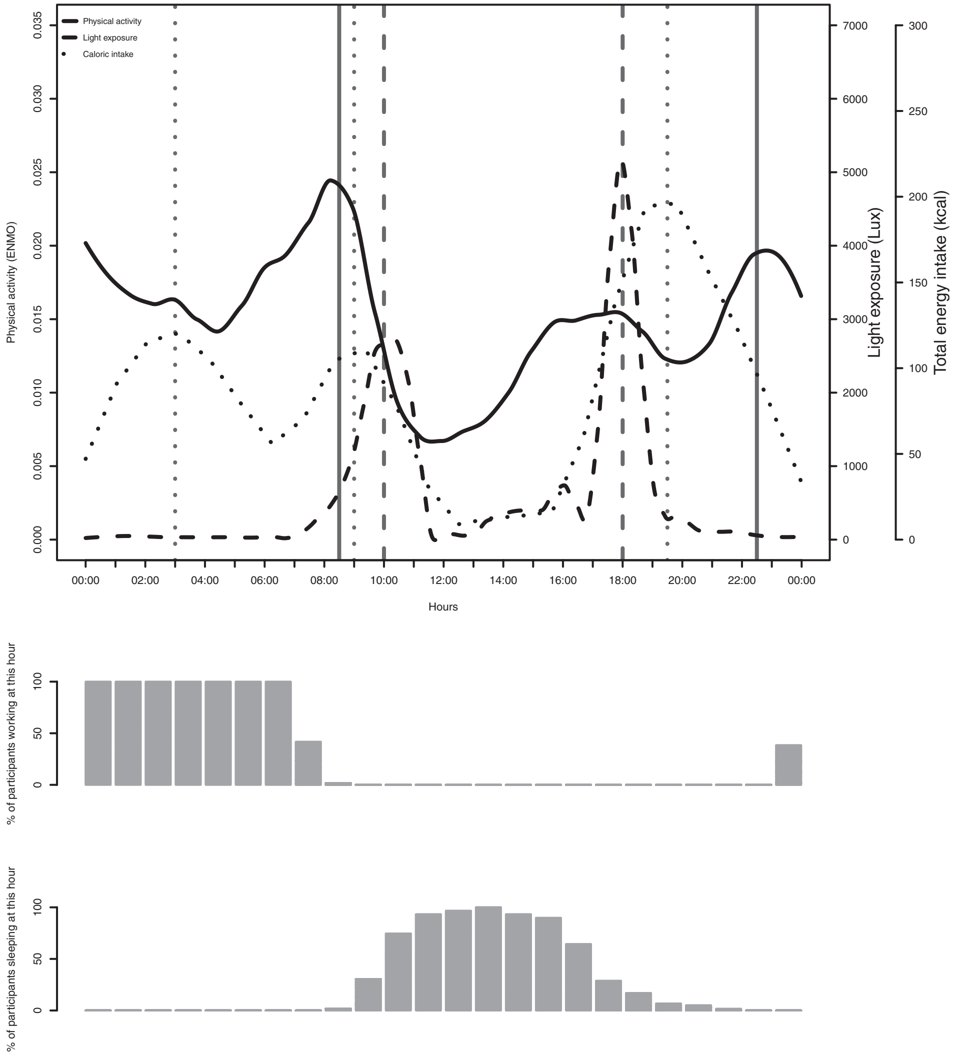

Figure 3. Night-shift workers during night-shift session (n = 69). Pattern of light intensity (lux per 10 s), total energy intake pattern (kcal h^{-1}), and activity pattern (ENMO scores per 60 s) over 24 h. Bar plots reflect the percentage of participants working at this particular hour and sleeping at this particular hour. Modes were manually added to reflect the midpoint of the peak of an exposure.

family demands). As a consequence of their working hours, night-shift workers generally woke up later than day workers and, therefore, had longer fasting periods and a longer time period between their largest meal and bedtime. However, night-shift workers ate after their shift around midnight (mode at 0000h). In experimental settings, food availability in the evening compared to the morning was related to a lower energy expenditure response (Romon et al., 1993) and body-weight gain, independent of 24-h calorie intake (Garaulet and Gómez-Abellán, 2014), which highlights the importance of timing of eating relative to a person's biological clock.

Night-shift workers did not significantly differ from day workers on MVPA, consistent with previous findings (Wang et al., 2012; Hulsegge et al., 2017). MVPA (equivalent to cycling at a slow pace) has shown robustness and ability for differentiating sedentary behaviors from mild-intensity physical activities in other research (Bakrania et al., 2016); yet, especially for cycling, we cannot exclude the possibility that it lacks sensitivity (Bakrania et al., 2016).

Night-shift workers had higher daylight levels than day workers. Our time-resolved data indicate that the majority of exposure to daylight was incurred before the

Table 3. Night-shift session compared to non-night-shift session within night-shift workers ($n = 69$).

Outcome	Estimate[a] (SE)	lcl, ucl 95%	*P* value*
Total caloric intake (mean/24 h)	122 (84)	−42, 286	0.147
Proteins (% of total energy 24 h)	0.01 (0.7)	−1.4, 1.4	0.987
Carbohydrates (% of total energy 24 h)	−0.9 (1.2)	−3.4, 1.5	0.444
Fats (% of total energy 24 h)	2.3 (1.2)	0.01, 4.7	0.057
Saturated fats (% of total energy 24 h)	1.1 (0.6)	−0.1, 2.3	0.077
Fibers (g over 24 h)	−0.2 (1.2)	−2.5, 2.1	0.895
Maximum fasting intensity (hours over 24 h)	−3.7 (0.53)	−4.7, −2.6	**<0.001**
Frequency (no. of meals >5 kcal over 24 h)	0.9 (0.3)	0.3, 1.5	**0.003**
Physical activity (% of time >MVPA threshold over 24 h)[b]	−11 (10)	−27, 7	0.217
Physical activity (% of self-reported time over 24 h)[b]	−24 (18)	−47, 7	0.121
Daylight exposure (% of time >500 lux over 48 h)[b]	−60 (15)	−70, −46	**<0.001**
Daylight exposure (% of time >1000 lux over 48 h)[b]	−71 (22)	−81, −66	**<0.001**
Sunlight exposure (% of time >10 000 lux over 48 h)[b]	−76 (28)	−86, −58	**<0.001**
Time spent outside during daylight (% of self-reported time over 48 h)[b]	−60 (14)	−70, −47	**<0.001**

Bold values indicate statistically significant *P* values at <0.05.

[a]Adjusted for age, BMI, education, chronotype, summer/wintertime.

[b]Log-transformed data.

**P*-value is based on mixed effect model (repeated measurements within participant).

start of the work shift. As night-shift workers generally started their working day later than day workers, we speculate that this group had more time to spend outdoors (increasing their chance of daylight) before the start of their shift. This effect was strongest during wintertime when there is minimal exposure to daylight after a 0900–1700h shift in the Netherlands.

Comparison between night-shift sessions and non-night-shift sessions among night-shift workers

Night-shift work did not affect total caloric intake, but did affect timing of eating, which is in line with previous findings (Esquirol et al., 2009; Antunes et al., 2010; Puttonen et al., 2010). In a study by de Assis et al. (2003a), 24-h patterns in caloric intake of the afternoon shift (comparable to our non-night-shift session) resembled the night shift, whereas in our study caloric intake patterns of the non-night-shift session of the night-shift workers resembled the day workers more than it resembled the night-shift session. We did find similar results regarding the increased frequency of eating moments for night-shift sessions compared to non-night-shift sessions (de Assis et al., 2003a). Our findings strengthen the hypothesis that night-shift workers tend to eat smaller portions (Antunes et al., 2010) and more high-fat snacks (Antunes et al., 2010; Hemiö et al., 2015) during the night-shift session, as fat intake was also higher, especially among obese participants. We observed a shorter maximum fasting period during the night-shift session compared to the non-night-shift session, which is related to negative effects on body composition (Heilbronn et al., 2005), energy metabolism (Heilbronn et al., 2005), and body weight (Gill and Panda, 2015).

Caloric intake peaked during the night for the night-shift session, which has been shown in a similar study before (de Assis et al., 2003a). As glucose tolerance is low during the night, eating at night has been hypothesized to increase the risk of diabetes (de Assis, et al., 2003b; Panda, 2016). Moreover, eating during the night can cause circadian misalignment, which can contribute to metabolic dysregulation and associated health problems (Eckel et al., 2015).

Participants were less physically active during the night-shift session compared to the non-night-shift session, particularly during summertime. Overall, physical activity levels were higher in summer. During night, participants might be restricted in their participation in social and leisure activities because the working schedule of night shifts is less accommodating (Atkinson et al., 2008). In addition, we observed higher light-exposure levels during the sleeping period of night-shift workers during the night-shift session compared to a non-night-shift session. Dim light conditions in the bedroom have previously been associated to significant structural differences in sleep, such as more shallow sleep and more frequent wakes (Cho et al., 2016).

An important aspect within diurnal patterns of light, physical activity, and caloric intake is the contrast between day and night or sleeping period and periods being awake. Low contrasts between day and night are referred to in the literature as weak zeitgebers (Martinez-Nicolas et al., 2014), which can result in chronodisruption and is therefore related to metabolic disorders (Martinez-Nicolas et al., 2014). We have found weak zeitgebers in the absence of darkness during the sleeping period and absence of light during the active period, frequent snacking, eating at night, and a less pronounced physical activity pattern over 24 h during the night-shift session. Therefore, we would recommend future research to focus on strategies to enhance day/night contrasts within night-shift workers. Strategies could include sleep hygiene aspects, such as the use of blackout curtains, or increasing fasting periods and decreasing activities during the time period participants should be sleeping.

The definition of a control group in a study of night-shift-work-related exposures

For several exposures, the effects observed between night-shift workers and day workers were not in the same direction as those observed between the night-shift session and the non-night-shift session. Although these differences in the direction of effect could perhaps be explained by some sort of compensation mechanism, the interpretation of the comparison between night-shift workers and day workers in our study requires some nuance. Day workers were selected as control group to assess whether night-shift workers working in an afternoon shift, at a time in their schedule they were least disrupted, incurred different exposure patterns compared to the general population. However, working hours and sleeping hours during an afternoon shift were not the same as those for day workers, and therefore, we cannot exclude that there was an acute influence of current working hours on the differences in exposure patterns observed between these groups. To acquire full insight into (variations in) exposure patterns among shift workers, we recommend that future studies extend our approach by including all possible shift types observed in the study population.

Collinearity between exposures

We observed moderate correlations between several exposure metrics. For instance, in day workers, daylight exposure was moderately correlated with lower total energy intakes and higher protein intake and weakly correlated with higher MVPA. MVPA was weakly correlated with lower percentages of fat intake. Within night-shift workers, we did not observe these correlations. During the night shift, carbohydrate intake was weakly correlated to daylight exposure, and protein intake was weakly correlated to MVPA. Collinearity between patterns became especially visible in the time-resolved measurements. All three exposures manifest themselves mainly during the time participants were awake, although for the night-shift session we saw also somewhat higher exposures during the period participants reported to be sleeping (this was true for all three exposures), probably because participants wake-up more often during their sleeping period and slept during the day in a relatively light environment. The day workers and shift workers showed similarities in reported sleep times (although the day workers woke up earlier), during a non-night-shift session most participants slept until at least 0600h. Besides sleep timing, working hours influence these exposure patterns as well, including associated commuting times from and to work. Participants were mainly exposed to daylight outside of working hours. In addition, daylight exposure patterns and total energy intake showed collinearity, as participants seemed to eat in relatively light environments. The time at which the shift starts also had a strong influence on physical activity patterns, because there seemed to be a peak during the time period where we expected participants to be commuting based on their work hours. Besides sleep and work times, social cues also influenced exposure patterns, especially the timing of eating, because independent of their sleep–wake cycle and work schedule participants had their main meal at the same time, around 1930h. The results of our study indicated that several exposure patterns were correlated, yet underlying factors contributing to the observed patterns differed from exposure to exposure. Focusing on these underlying factors might contribute to the untangling of these exposures in future studies and relate them to health outcomes. Intervention studies can also focus on these underlying factors. For instance, because working hours are related to light-exposure patterns, interventions could focus on working schedules. Dietary intervention could focus on social cues, as these play a role in meal timing.

Self-reported and measured data were not highly correlated. For instance within day workers, light exposure >10 000 lux was weakly correlated ($r = 0.3$) with self-reported daylight exposure (Appendix II in Supplementary data, available at *Annals of Work Exposures and Health* online). Within shift workers, MVPA was also weakly correlated ($r = 0.27$) with self-reported physical activity. In other cases, we found no correlations between self-reported and measured exposures, for instance night-shift workers' self-reported time spent outside and measured light outcomes were not correlated ($r = 0.02$). However, caution should be exercised when interpreting these results, because the quality of our sensors cannot be considered the gold standard. Ideally, physical activity should be measured for at least seven consecutive days. In addition, we recommend more sensitive light sensors, including the ability to differentiate blue light. Vice versa, the fact that we did not find strong collinearity between self-reported data and measured exposures should be taken into consideration when interpreting the results of questionnaires and indicates that the validation of questionnaires in a smaller subset using measurement data of interest. Also, because we mainly found differences in diurnal patterns, large cohort studies studying the impact of night-shift work should focus on these shifts in zeitgebers. For example, the Dutch Nightingale cohort collected items regarding warm-meal timing, regularity of eating and sleeping, activity after the last night shift worked, and light circumstances specifically during work time and sleep time (Pijpe et al., 2014).

Conclusions

On the basis of aggregated measurements, we observed similar physical activity levels and 24-h caloric intake, and a higher daylight exposure when comparing night-shift workers to day workers. Among night-shift workers, there was less daylight exposure during the night-shift session compared to the non-night-shift session. Time-resolved patterns better describe differences in exposures than averaged exposure estimates. From our time-resolved data, it became visible that sleeping hours and working hours (related to the time at which people commute from and to work) affected the exposure patterns of diet, physical activity, and daylight. Timing of dinner seemed primarily governed by social conventions. These different underlying factors might help us untangle night-shift-work-related exposures in future studies.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of Interest

The authors declare no conflict of interest relating to the material presented in this article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors. We assure that the manuscript is original work, has not been previously published whole or in part, and is not under consideration for publication elsewhere. All authors have disclosed any potential competing interests regarding the submitted article and the nature of those interests, have read the manuscript, agree that the work is ready for submission to a journal, and accept responsibility for the manuscript's contents.

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