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Original Article

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Light Exposure during Days with Night, Outdoor, and Indoor Work

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Abstract

Objective: To assess light exposure during days with indoor, outdoor, and night work and days off work.

Methods: Light intensity was continuously recorded for 7 days across the year among indoor (*n* = 170), outdoor (*n* = 151), and night workers (*n* = 188) in Denmark (55–56°N) equipped with a personal light recorder. White light intensity, duration above 80, 1000, and 2500 lux, and proportion of red, green, and blue light was depicted by time of the day and season for work days and days off work.

Results: Indoor workers' average light exposure only intermittently exceeded 1000 lux during daytime working hours in summer and never in winter. During daytime working hours, most outdoor workers exceeded 2500 lux in summer and 1000 lux in winter. Night workers spent on average 10–50 min >80 lux when working night shifts. During days off work, indoor and night workers were exposed to higher light intensities than during work days and few differences were seen between indoor, outdoor, and night workers. The spectral composition of light was similar for indoor, outdoor, and night workers during days at and off work.

Conclusion: The night workers of this study were during night hours on average exposed for a limited time to light intensities expected to suppress melatonin. The indoor workers were exposed to light levels during daylight hours that may reduce general well-being and mood, especially in winter. Outdoor workers were during summer daylight hours exposed to light levels comparable to those used for the treatment of depression.

Keywords: chronobiology; exposure; leisure; light at night; occupational exposure; outdoor work; shift work; sunlight

Introduction

Bright light exposure has shown beneficial effects on well-being, mood, vitality, and learning ability (Espiritu *et al.*, 1994; Hubalek *et al.*, 2010; Hahn *et al.*, 2011; Figueiro and Rea, 2014; Marqueze *et al.*, 2015). Nonseasonal depression may respond to light therapy >2500 lux applied in the morning (Tuunainen *et al.*, 2004). One-hour outdoor morning light exposure has been reported to have a beneficial effect on seasonal affective disorder (SAD) (Wirz-Justice *et al.*, 1996). On the other hand, no preventive effect of light exposure has been shown for SAD (Nussbaumer *et al.*, 2015). Light suppresses melatonin dependent on duration, intensity, and spectrum of the exposure and the largest effect is seen at night (Bojkowski *et al.*, 1987; Rea *et al.*, 2005; Figueiro *et al.*, 2006; Revell and Skene, 2007; Wood *et al.*, 2013; Rea and Figueiro, 2014). Exposure to a single 6.5 h episode of evening light from a fluorescent lamp suppresses plasma melatonin concentration with increasing intensity following a logistic dose response curve with minimal suppression <80 lux (Zeitzer *et al.*, 2000). We recently showed that nocturnal exposure to light >80 lux during the recent 30 min mediated some of the decreased salivary melatonin concentration seen in night workers (Daugaard *et al.*, 2017). Light at night may also phase advance as well as phase delay circadian rhythm (Shanahan *et al.*, 1997; Stevens *et al.*, 2013) and increase alertness (Cajochen *et al.*, 2000). These nonvisual effects are more sensitive to blue light (Brainard *et al.*, 2001; Wood *et al.*, 2013) whereas red light may increase alertness and performance without suppressing melatonin (Figueiro *et al.*, 2016).

Studies of light exposure levels in occupational groups have mainly been conducted at the northern hemisphere between 40 and 50°N. They have shown light intensity levels of ~100–300 lux during daytime office work with the lower values recorded during winter (Hubalek *et al.*, 2010; Figueiro and Rea, 2014). Higher daytime intensities have been reported among indoor, hospital workers (~100–800 lux) and factory and railway workers (~800–2000 lux) (Burch *et al.*, 2005; Papantoniou *et al.*, 2014).

Office workers, nurses, and other indoor workers have been reported to spend ~15 min >1000 lux during summer working hours (Heil and Mathis, 2002; Hubalek *et al.*, 2010). Corresponding values of 0.5–2 h during summer and 0.5–1 h during winter waking hours have been reported (Savides *et al.*, 1986; Koller *et al.*, 1993; aan het Rot *et al.*, 2008; Crowley *et al.*, 2015).

Average light intensities of ~50 lux have been measured during night work (Dumont *et al.*, 2012; Papantoniou *et al.*, 2014). A single study has shown that outdoor workers on average spend ~3 h >1000 lux during summer (Dumont and Beaulieu, 2007). Light exposure has constantly been reported higher on indoor workers' days off than on their work days (Koller *et al.*, 1993; Borugian *et al.*, 2005; aan het Rot *et al.*, 2008; Hubalek *et al.*, 2010; Crowley *et al.*, 2015). During days off, the average duration >1000 lux was ~2–2.5 h in summer (Hubalek *et al.*, 2010; Crowley *et al.*, 2015) and 1.5 h >1000–1500 lux in winter (Koller *et al.*, 1993; Crowley *et al.*, 2015).

The objectives of this study are to assess light exposure intensity and exposure duration above different thresholds during days with indoor, outdoor, and night work and days off work.

Materials and methods

Study setup

Participants (N = 535) were recruited through employers with the aim to recruit equal numbers of indoor, outdoor, and night workers. They were followed for seven consecutive days, starting at different days of the week and at different times of the day depending on their work schedules. Participants completed a questionnaire at entry and kept a diary during all 7 days and light intensities were continuously recorded with a light recorder.

Data collection was carried out in Denmark (55–56°N) from March 2012 until May 2013. In Denmark, winter solstice occurs on the 21st or 22nd of December when the day length is 7 h and 1 min. Summer solstice occurs on the 20th or 21st of June when the day length is 17 h and 33 min. The monthly sunshine hours vary between 45 h in December and 240 h in July. The daily mean temperature varies between 1.2°C in February and

17.4°C in July. The mean wind speed is between 4 and 5 m/s throughout the year (www.DMI.dk).

All participants gave written informed consent and the study was approved by the Danish Data Protection Agency (J.nr. 2011-41-6850) and the Central Denmark Regional Ethics Committee (M-20110214).

Participants and measurement days

Based on the diary information, we defined a day with ≥120 min of work between 00:00 and 05:00 h as a night work day and a day with ≥120 min of outdoor work as an outdoor work day. A work day not fulfilling these criteria was classified as an indoor work day. A day with no recorded work was classified as a day off work. To examine if light exposure on days off work differed between participants working night, outdoor, or indoor shifts, participants were classified into three job groups. Participants with ≥1 day of night work were classified as night workers, participants with no night work days and ≥1 outdoor work day as outdoor workers and participants with no night and no outdoor work days as indoor workers.

Twenty-six participants with incomplete diary information to classify at least 1 day as an indoor, outdoor or night work day were excluded. The final study population then comprised 509 participants (170 indoor workers, 151 outdoor workers, 188 night workers). A total of 485 participants provided light measurements from workdays and 485 from days off work (Table 1). In the analyses, we only included days with indoor work for indoor workers, outdoor work for outdoor workers, and night work for night workers. All days off work were included from the three job groups.

Women comprised 76% of the indoor workers, 52% or the outdoor workers, and 82% of the night workers (overall 72%). The mean age was 45 (range 18–69) years among indoor workers, 41 (18–67) years among outdoor workers and 41 (24–64) years among night workers (overall 42, 18–69, years). Indoor workers included hospital employees, teachers, child care workers, factory workers, residential social workers, mechanics, gardeners, craftsmen, and work environment inspectors. Outdoor workers included child care workers, gardeners, craftsmen, teachers, and physiotherapists. Night workers included hospital employees, factory workers, and residential social workers.

Questionnaire and diary

At study start, participants reported their occupation. Daily, they recorded bedtime, time of waking up, and working hours. For each hour of the day, they reported if the light recorder was not worn for >20 min and if they had spent >20 min outdoors.

Light assessment

Participants were instructed to wear a Philips Respironics Actiwatch Spectrum (Actiwatch) outside clothes on the upper arm during all hours awake except during showers and swimming. They were instructed to keep the Actiwatch next to the bed with the front pointing upwards while sleeping for 2 days and to wear the Actiwatch on the wrist while sleeping for the remaining 5 days to estimate sleep quality by actigraphy. Only light measurements when the Actiwatch was kept next to the bed during sleep were included because we were only interested in the ambient light levels.

The Actiwatch sensor measures arbitrary light intensity in the red, blue, and green wavelength bands. The white light (lux) output is derived from the light intensities received by these three bands. Light and actigraphy were recorded with 1-min epochs.

All Actiwatches were calibrated using a side-by-side calibration method as described by Markvart *et al.* (2015). The white light output was calibrated under overcast sky conditions against a cosine corrected photometer with a spectral sensitivity that closely relates to the luminosity function V (λ) established by the Commission Internationale de l'Éclairage (CIE). We refer to the calibrated white light output as light. The Actiwatch sensor outputs of red, green, and blue light were calibrated against the side-by-side average output. The spatial and wavelength band sensitivity of red,

Table 1. Numbers of indoor, outdoor, and night workers.

Type of the day	Indoor workers		Outdoor workers		Night workers		All workers	
	Workers	Days	Workers	Days	Workers	Days	Workers	Days
Work day	169	690	135	366	181	420	485	1476
Day off work	167	454	140	320	178	400	485	1174
All days[a]	170	1144	151	686	188	820	509	2650

[a]166 indoor workers, 124 outdoor workers, and 171 night workers provided light measurements from both a work day and a day off work.

green, and blue radiation have been described earlier (Price *et al.*, 2012; Figueiro *et al.*, 2013).

In total, 2 847 263 1-min light measurements were collected from days with indoor, outdoor, and night work, and days off work fulfilling the earlier reported criteria. Data were omitted when participants were awake and the Actiwatch was reported not worn (168 391 min, 5.9%) or if no physical activity was recorded for 20 min by actigraphy (164 114 min, 5.8%). In total, 2 514 758 1-min light measurements obtained during 2650 days were then available for analyses of light intensity. This corresponded with an average of 15 h and 45 min of light measurements per day.

Out of all measurements, 0.9% showed a light intensity of 0.000 lux, while 22.9% showed an intensity ≤1.200 lux corresponding with the highest level recorded when all Actiwatches were placed in complete darkness for four 8-h sessions (Markvart *et al.*, 2015). We used the exact value of all measurements instead of assigning new values to measurements below a certain limit of detection to keep as much information as possible in the data (Whitcomb and Schisterman, 2008).

Data were also analyzed as the duration >3 light intensity thresholds: 80, 1000, and 2500 lux. For these analyses, we required ≥90% completeness of measurement for each of four 6-h intervals (00:00–05:59 h, 06:00–11:59 h, 12:00–17:59 h, 18:00–23:59 h). In total, 1 573 729 1-min light measurements from 4461 6-h intervals, and 2290 days were included from 504 participants.

Statistical analysis

We smoothed the 1-min light intensities by a moving window equal to the arithmetic mean of the intensities of the last 20 min for each measurement day. The arithmetic means of these values were plotted by time of the day for days with indoor, outdoor, and night work and days off work and stratified by season as defined by start and end dates of European daylight saving time. To simplify our language we usually do not report that results were for days of indoor, outdoor or night work but for indoor, outdoor, and night workers. We plotted the percentages of red, green, and blue light in a similar way as light intensity.

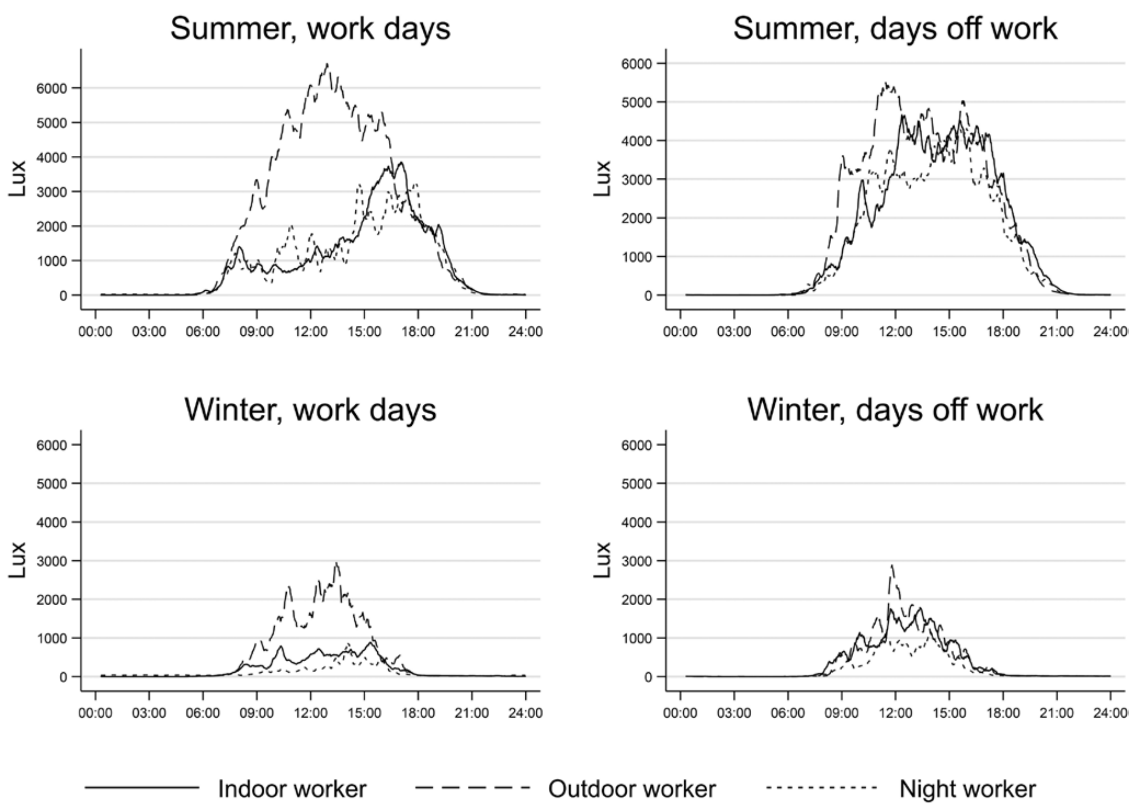

Figure 1. Arithmetic mean light intensities (lux) for indoor, outdoor, and night workers during work days, days off work and stratified by season.

We also tabulated arithmetic mean, median, geometric mean, and geometric standard deviation of light intensity computed across four 6-h intervals: 00:00–05:59 h (night), 06:00–11:59 h (morning), 12:00–17:59 h (afternoon), and 18:00–23.59 h (evening) separately for work days and days off and stratified by summer and winter.

Duration (minutes) above 80, 1000, and 2500 lux was tabulated in a similar way as light intensity. These thresholds were decided on to represent the thresholds for melatonin suppression and induction of alertness during night (Cajochen *et al.*, 2000; Zeitzer *et al.*, 2000), staying outdoor versus indoor during daytime (Partonen and Lonnqvist, 2000; Heil and Mathis, 2002; aan het Rot *et al.*, 2008; Hubalek *et al.*, 2010; Smolders *et al.*, 2013; Crowley *et al.*, 2015; Figueiro *et al.*, 2017), and the intensity recommended for light therapy for depression (Tuunainen *et al.*, 2004).

Light intensities and duration above the three thresholds showed right-skewed distributions. An intensity of 0.000 lux was therefore replaced by 0.001 lux and a duration of 0 min by 1 min before log transformation before further analyses. In multivariate linear regression analyses, we estimated the percentage differences between night, outdoor, and indoor workers with the latter as the reference. Analyses of light intensities were adjusted by sampling hour within the four 6-h intervals. Analyses were carried out with a mixed procedure with an autoregressive structure with participant as an independent random variable because each participant was measured multiple times. The models were evaluated by inspecting residual and leverage plots. All analyses were carried out using STATA 13.0 (StataCorp, College Station, TX, USA).

Results

Figure 1 depicts arithmetic mean light intensities for indoor, outdoor, and night workers across days with indoor, outdoor, and night work (work days), days off work and stratified by season. On summer workdays, mean light intensities of outdoor workers showed a maximum of 6000 lux around noon, which was two to three times the maximum intensity observed ~17:00 h for indoor and night workers. Outdoor workers' mean light intensity exceeded 2500 lux between 8:00 and 17:30 h;

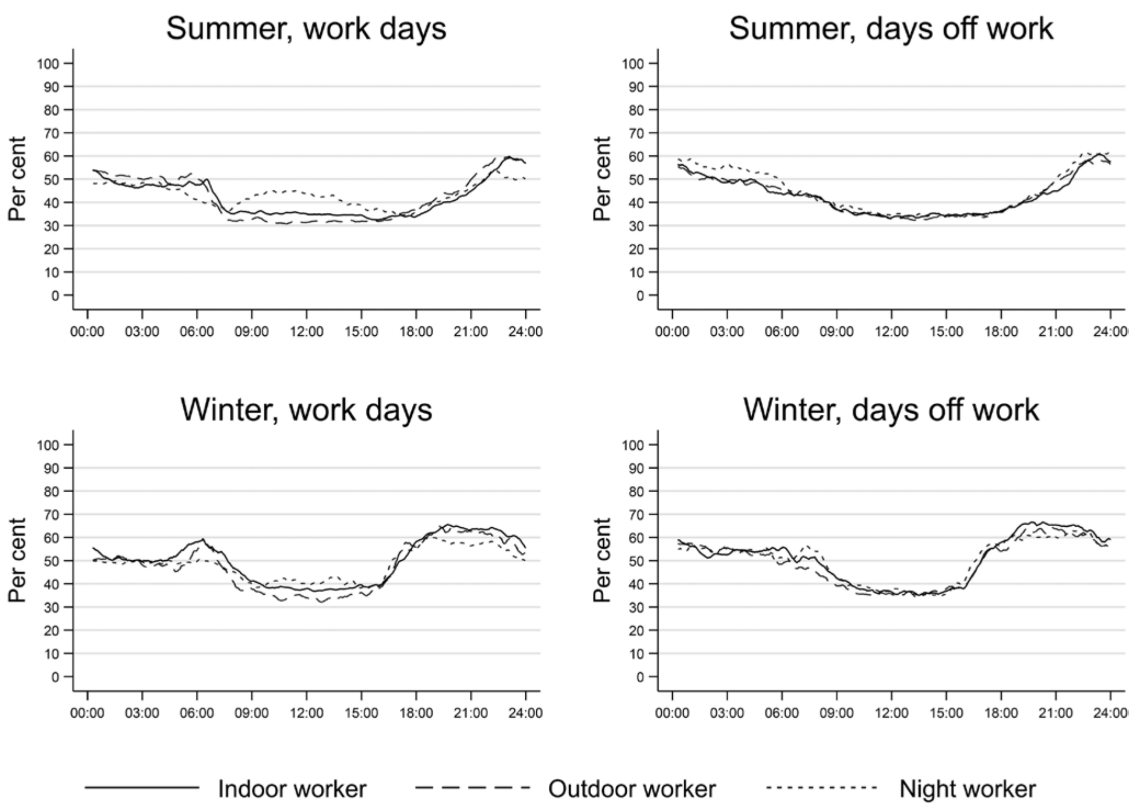

Figure 2. Red light proportion (%) of total light exposure for indoor, outdoor, and night workers during work days, days off work and stratified by season.

this was only seen between 15:00 and 17:00 h for indoor workers. On summer days off work, outdoor workers were exposed to slightly higher light intensities than night and indoor workers in the morning with a maximum of 5000 lux. All three job groups peaked between 12:00 and 16:00 h and showed mean light intensities exceeding 2500 lux from 12:00 until ~18:00 h.

On winter work days, mean light intensities were also higher among outdoor than among indoor and night workers during daytime and exceeded 1000 lux from ~10:00 h until ~15:00 h but only briefly exceeded 2500 lux. Indoor and night workers' exposure showed no noticeable peaks and never exceeded 1000 lux. On winter days off work, few differences were seen between the three job groups during daytime as outdoor workers showed lower and indoor and night workers higher mean light intensities than on workdays.

Figures 2–4 depict the relative composition (%) of red, green, and blue light across the day on work days and days off work separately for summer and winter. During daylight hours, the proportion of green and to some extent also blue light was higher than during night hours while the opposite was seen for red light. Few differences were seen between the three job groups.

Table 2 presents 6-h average light intensities expressed by arithmetic and geometric means and medians. On work days, outdoor workers' average light intensity was >4000 lux during afternoons (12:00–17:59 h) in summer and >1000 lux in winter. During night work (00:00–05:59 h), average light intensities among night workers were ~10–25 and 20–40 lux in summer and winter, respectively. These intensities were much higher than the levels recorded for indoor workers during the same hours. On days off work, outdoor workers were exposed to lower light intensities in summer evenings (18:00–23:59 h) and higher light intensities in winter nights compared with indoor workers.

Tables 3–5 show durations above 80, 1000, and 2500 lux for indoor, outdoor, and night workers during work days and days off work. Night workers spent on average ~10–30 min >80 lux during night work in summer and 10–50 min in winter. This was almost 10-fold the durations seen for indoor workers during night (Table 3). On days off work, few differences were seen between night workers and indoor workers.

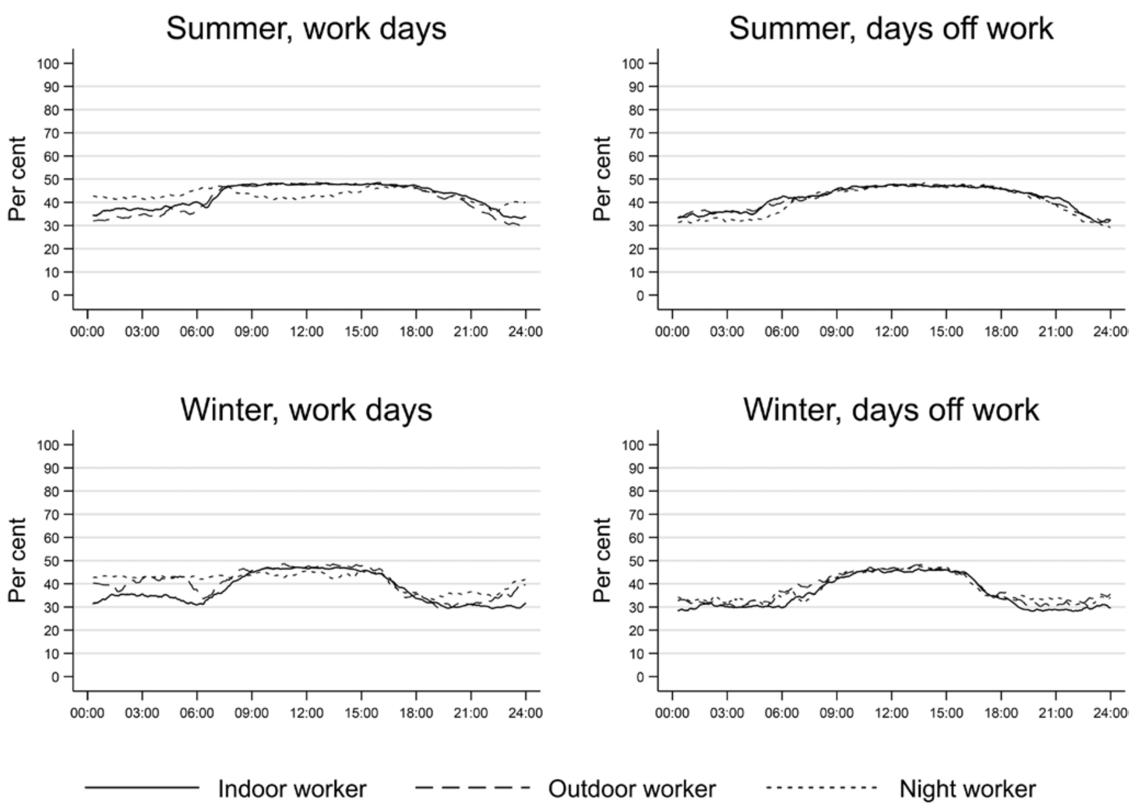

Figure 3. Green light proportion (%) of total light exposure for indoor, outdoor, and night workers during work days, days off work and stratified by season

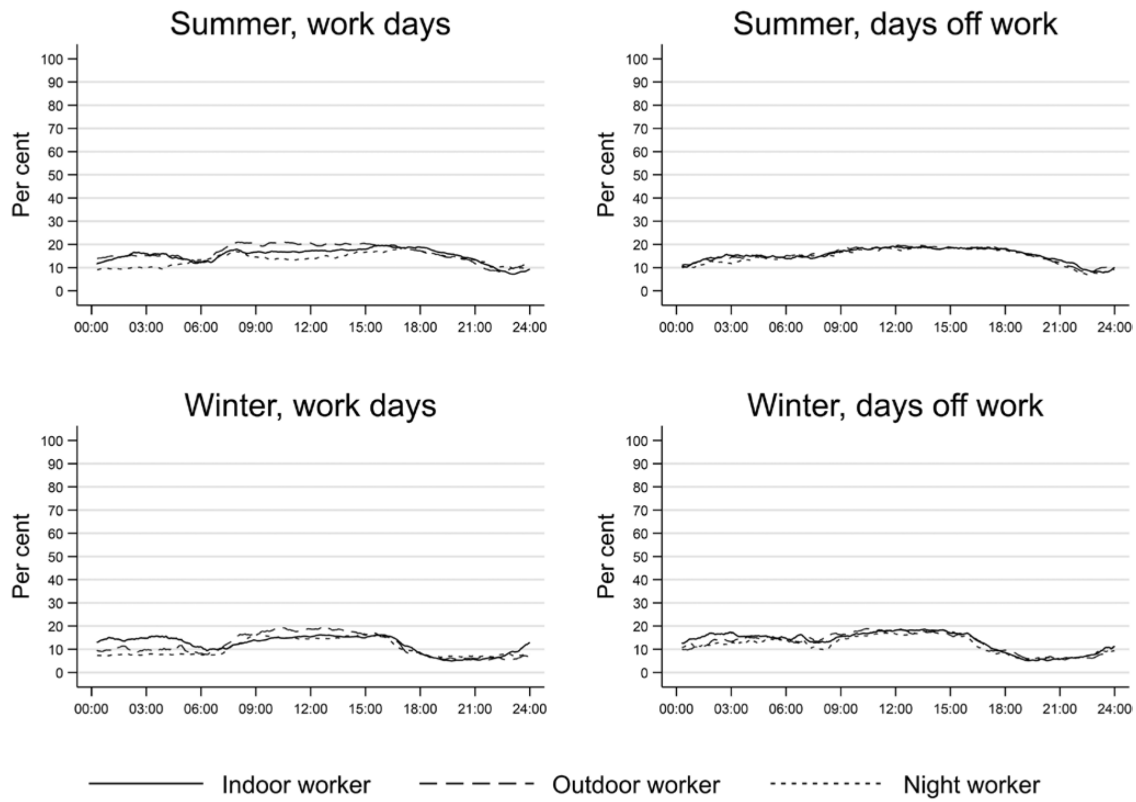

Figure 4. Blue light proportion (%) of total light exposure for indoor, outdoor, and night workers during work days, days off work and stratified by season.

Outdoor workers spent on average ~100–140 min >1000 lux during mornings in summer and ~30–60 min in winter when at work (Table 4). Indoor workers' corresponding values were ~10–40 min in summer and 5–10 min in winter. Outdoor workers spent on average ~25–80 min >2500 lux during mornings in summer and 10–60 min in winter (Table 5). These values were about eight and four times the values seen for indoor workers. On days off work, outdoor workers spent on average ~20–80 min >2500 lux during summer mornings and 40–80 min >80 lux during summer evenings. Otherwise, outdoor workers experienced light exposure similar to indoor workers on days off work, regardless of season.

Discussion

Indoor workers' mean light exposure intensity intermittently exceeded 1000 lux during Danish standard day shift hours in summer and never in winter. Contrary to this, outdoor workers exceeded 2500 lux in summer and 1000 lux in winter during all day shift hours. Compared with indoor workers, outdoor workers spent 8- and 4-fold longer time >2500 lux during summer and winter mornings, respectively. Night workers spent on average ~10–50 min >80 lux during night, which was ~8-fold more than indoor workers during the same hours. During days off work, indoor and night workers were exposed to more light than during work days, and only marginal differences were seen between indoor, outdoor, and night workers. The distribution of green, blue, and red light showed few differences between indoor, outdoor, and night workers.

The time indoor workers spent >1000 lux was comparable to results from previous field studies even if these were conducted at lower latitudes (aan het Rot *et al.*, 2008; Hubalek *et al.*, 2010; Smolders *et al.*, 2013; Crowley *et al.*, 2015), but some included no winter measurement (Hulabek et al., 2010, Crowley *et al.*, 2015) and Heil and Mathis (2002) reported an average of 36 min during a 24-h period in September.

Our observations that outdoor workers were exposed to much higher light levels during work than indoor workers did not come as a surprise and were in accordance with a study of Canadian outdoor workers

Table 2. Six-hour light intensities of indoor, outdoor, and night workers during work days and days off work by season and time of the day.

Time period by season and type of the day		Indoor workers (N = 170)) Light intensity (lux)					Outdoor workers (N = 151) Light intensity (lux)							Night workers (N = 188) Light intensity (lux)						
		N[a]	AM[b]	Median	GM[c]	GSD[d]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]
Summer																				
00:00–05:59	Work day	688	13	0.2	0.3	17	513	5.2	0.2	0,2	22	−47	0.05	1240	25	18	13	4	1298	<0.01
	Day off work	646	5	0.2	0.2	15	675	5.5	0.2	0.2	14	−43	0.05	520	3	0.2	0.2	17	−3	0.92
06:00–11:59	Work day	1880	755	242	223	6	1466	3148	944	643	11	159	<0.01	855	753	53	4	21	−57	<0.01
	Day off work	1138	1511	209	142	18	984	2733	219	149	32	14	0.50	957	1623	168	92	30	−27	0.11
12:00–17:59	Work day	2315	2428	562	661	5	1559	4715	2089	1478	7	80	<0.01	843	2085	307	174	24	−75	<0.01
	Day off work	1328	4064	949	912	7	1120	3986	969	732	11	−17	0.25	1122	3176	781	719	8	−12	0.48
18:00–23:59	Work day	2110	596	28	33	13	1298	528	16	17	19	−50	<0.01	991	498	30	33	9	23	0.14
	Day off work	1245	573	26	29	13	1,033	476	11	16	16	−35	0.01	1096	407	18	21	11	−2	0.88
Winter																				
00:00–05:59	Work day	465	2	0.2	0.2	12	141	2.8	0.2	0.3	10	218	0.01	1056	38	22	19	3	6951	<0.01
	Day off work	555	2	0.2	0.1	16	310	1.5	0.2	0.2	8	105	0.03	353	4	0.3	0.5	10	315	<0.01
06:00–11:59	Work day	1334	308	107	85	6	399	867	183	166	8	87	<0.01	726	79	19	12	11	−51	<0.01
	Day off work	903	611	49	29	28	474	708	39	27	25	14	0.53	652	351	39	24	20	−22	0.19
12:00–17:59	Work day	1626	472	136	121	5	422	1301	283	221	8	41	0.04	718	232	24	19	12	−72	<0.01
	Day off work	1040	775	106	101	9	538	787	88	92	9	−16	0.28	806	465	77	75	8	−9	0.57
18:00–23:59	Work day	1431	19	8.5	6	6	348	14	7	6	4	−10	0.46	868	20	12	9	4	55	<0.01
	Day off work	976	16	6.8	5	6	506	13	6	5	4	15	0.44	730	12	6	5	5	3	0.84

[a]Hours with light measurements.
[b]Arithmetic mean.
[c]Geometric mean.
[d]Standard deviation of geometric mean.
[e]Percentage difference and P-values computed from mixed linear regression analyses comparing log light intensity with indoor workers as the reference and adjusted for hour of sampling.

Table 3. Duration (minutes) >80 lux for indoor, outdoor, and night workers during work days and days off work by season and time of the day.

Time period by season and type of the day		Indoor workers (N = 170)) Duration (minutes)					Outdoor workers (N = 151) Duration (minutes)							Night workers (N = 185) Duration (minutes)						
		N[a]	AM[b]	Median	GM[c]	GSD[d]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]	N	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]
Summer																				
00:00–05:59	Work day	78	2	0	1	2	62	1	0	1	2	−10	0.57	157	26	14	12	4	774	<0.01
	Day off work	75	2	0	1	2	80	2	0	1	2	8	0.50	60	1	0	1	2	−2	0.89
06:00–11:59	Work day	196	225	237	207	2	177	254	263	245	1	19	0.14	56	79	50	43	4	−79	<0.01
	Day off work	63	165	166	148	2	60	167	164	120	3	−18	0.33	49	144	154	98	4	−35	0.04
12:00–17:59	Work day	320	266	285	256	1	215	279	297	268	1	5	0.49	48	194	204	141	3	−46	<0.01
	Day off work	161	258	273	246	1	140	237	256	206	2	−15	0.01	136	243	258	229	1	−7	0.29
18:00–23:59	Work day	162	95	82	64	3	82	71	60	37	4	−38	0.01	123	84	75	58	3	−11	0.49
	Day off work	108	90	81	60	3	85	77	65	42	4	−17	0.40	90	69	55	40	4	−37	0.04
Winter																				
00:00–05:59	Work day	62	1	0	1	2	17	1	0	1	2	−1	0.98	161	53	13	14	7	847	<0.01
	Day off work	69	1	0	1	2	40	0	0	1	1	−3	0.73	35	0	0	1	1	−1	0.96
06:00–11:59	Work day	129	159	168	138	2	47	175	171	160	2	11	0.64	49	62	23	24	5	−84	<0.01
	Day off work	39	129	125	103	2	29	111	108	79	3	−19	0.46	26	85	70	50	4	−43	0.05
12:00–17:59	Work day	234	178	180	162	2	57	185	194	173	1	10	0.55	43	80	53	42	4	−73	<0.01
	Day off work	125	145	137	115	2	61	137	136	104	2	−9	0.48	98	138	128	111	2	−6	0.65
18:00–23:59	Work day	102	19	8	7	4	21	18	5	6	5	−12	0.73	88	22	13	9	4	26	0.29
	Day off work	65	14	6	6	4	34	11	3	4	4	−38	0.14	63	11	2	4	4	−40	0.06

[a]Six-hour periods with light measurements.
[b]Arithmetic mean.
[c]Geometric mean.
[d]Standard deviation of geometric mean.
[e]*P*-values and percentage difference computed from mixed linear regression analyses comparing log minutes with indoor workers as the reference group.

Table 4. Duration (minutes) >1000 lux for indoor, outdoor, and night workers during work days and days off work by season and time of the day.

Time period by season and type of the day		Indoor workers (N = 170))					Outdoor workers (N = 151)							Night workers (N = 185)						
		Duration (minutes)					Duration (minutes)							Duration (minutes)						
		N[a]	AM[b]	Median	GM[c]	GSD[d]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]
Summer																				
00:00–05:59	Work day	78	1	0	1	2	62	0	0	1	1	−8	0.09	157	0	0	1	1	−8	0.04
	Day off work	75	0	0	1	1	80	0	0	1	1	0.0[d]	—	60	0	0	1	1	0.0[f]	—
06:00–11:59	Work day	196	35	22	16	4	177	137	124	104	2	459	<0.01	56	23	11	7	5	−59	<0.01
	Day off work	63	51	28	27	4	60	77	67	36	5	44	0.21	49	46	34	25	4	−18	0.49
12:00–17:59	Work day	320	80	75	61	2	215	151	152	125	2	103	<0.01	48	82	66	42	5	−32	0.01
	Day off work	161	116	98	77	3	140	117	102	76	3	3	0.85	136	108	89	78	3	2	0.88
18:00–23:59	Work day	162	29	15	9	6	82	23	6	7	6	−3	0.91	123	21	5	6	6	−25	0.25
	Day off work	108	25	8	7	6	85	22	6	6	6	−3	0.92	90	17	4	5	5	−26	0.26
Winter																				
00:00–05:59	Work day	62	0	0	1	1	17	0	0	1	1	0	1.00	161	0	0	1	1	3	0.19
	Day off work	69	0	0	1	1	40	0	0	1	1	0.0[d]	—	35	0	0	1	1	0.0[f]	—
06:00–11:59	Work day	129	12	2	4	5	47	56	47	30	5	600	<0.01	49	7	0	2	4	−55	0.01
	Day off work	39	36	17	11	6	29	40	15	12	7	9	0.86	26	18	11	7	5	−21	0.62
12:00–17:59	Work day	234	23	11	9	5	57	62	52	43	3	358	<0.01	43	14	1	4	5	−57	0.01
	Day off work	125	34	20	13	5	61	37	21	13	6	−4	0.88	98	31	19	14	4	−7	0.76
18:00–23:59	Work day	102	0	0	1	1	21	0	0	1	1	−3	0.55	88	0	0	1	1	−3	0.33
	Day off work	65	0	0	1	1	34	0	0	1	1	0.0[d]	—	63	0	0	1	1	0.0[f]	—

[a]Six-hour periods with light measurements.
[b]Arithmetic mean.
[c]Geometric mean.
[d]Standard deviation of geometric mean.
[e]*P*-values and percentage difference computed from mixed linear regression analyses comparing log minutes with indoor workers as the reference group.
[f]No measurements >1000 lux.

Table 5. Duration (minutes) >2500 lux for indoor, outdoor, and night workers during work days and days off work by season and time of day.

Time period by season and type of the day		Indoor workers (N = 170))					Outdoor workers (N = 151)							Night workers (N = 185)						
			Duration (minutes)					Duration (minutes)							Duration (minutes)					
		N[a]	AM[b]	Median	GM[c]	GSD[d]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]	N[a]	AM[b]	Median	GM[c]	GSD[d]	% diff[e]	P-value[e]
Summer																				
00:00–05:59	Work day	78	0	0	1	1	62	0	0	1	1	0.0[f]	—	157	0	0	1	1	0.0[f]	—
	Day off work	75	0	0	1	1	80	0	0	1	1	0.0[f]	—	60	0	0	1	1	0.0[f]	—
06:00–11:59	Work day	196	14	5	5	4	177	137	124	50	4	846	<0.01	56	11	2	4	4	−31	0.10
	Day off work	63	33	14	11	6	60	77	67	24	6	127	0,01	49	30	17	12	5	4	0.91
12:00–17:59	Work day	320	48	40	29	3	215	151	152	77	3	157	<0.01	48	54	40	22	6	−27	0.11
	Day off work	161	83	58	43	4	140	117	102	41	4	1	0,96	136	74	58	43	4	3	0.89
18:00–23:59	Work day	162	16	3	5	5	82	23	6	4	5	−12	0,61	123	11	1	3	5	−22	0.28
	Day off work	108	12	0	3	5	85	22	6	3	5	−4	0,87	90	8	0	2	4	−29	0.14
Winter																				
00:00–05:59	Work day	62	0	0	1	1	17	0	0	1	1	0.0[f]	—	161	0	0	1	1	0.0[f]	—
	Day off work	69	0	0	1	1	40	0	0	1	1	0.0[f]	—	35	0	0	1	1	0.0[f]	—
06:00–11:59	Work day	129	5	0	2	3	47	56	47	11	5	436	<0.01	49	4	0	1	3	−28	0.15
	Day off work	39	19	3	5	5	29	40	15	6	6	2	0.96	26	7	1	3	4	−38	0.27
12:00–17:59	Work day	234	9	1	3	4	57	62	52	14	5	355	<0.01	43	6	0	2	4	−38	0.07
	Day off work	125	17	4	5	5	61	37	21	6	6	14	0.65	98	12	2	4	5	−28	0.19
18:00–23:59	Work day	102	0	0	1	1	21	0	0	1	1	0.0[f]	—	88	0	0	1	1	0.0[f]	—
	Day off work	65	0	0	1	1	34	0	0	1	1	0.0[f]	—	63	0	0	1	1	0.0[f]	—

[a]Six-hour periods with light measurements.
[b]Arithmetic mean.
[c]Geometric mean.
[d]Standard deviation of geometric mean.
[e]P-values and percentage difference computed from mixed linear regression analyses comparing log minutes with indoor workers as the reference group.
[f]No measurements >2500 lux.

(Dumont and Beaulieu, 2007). Those workers reached a maximum exposure level of ~3000 lux and spent ~3 h >1000 lux during summer day work. This was about four times the exposure levels observed for indoor workers and only slightly higher than the values we observed.

In agreement with previous studies from Canada and Spain, night workers in our study were exposed to average light intensities during night work of ~10–50 lux that was higher than day workers during the same hours when most of them were expected to be sleeping (Grundy *et al.*, 2011; Papantoniou *et al.*, 2014). Our observation that night workers spent shorter time above 80, 1000, and 2500 lux between 06:00 and 18:00 h than indoor workers was in agreement with some (Koller *et al.*, 1993; Burch *et al.*, 2005; Papantoniou *et al.*, 2014), but not all previous studies (Borugian *et al.*, 2005; Dumont *et al.*, 2012).

The percentage of green and blue light increased during daylight hours, importantly also among the indoor workers and there were only small differences between indoor and outdoor workers. This may indicate that light from windows is an important predictor of the spectral composition during daylight hours because windowless workplaces are generally not permitted in Denmark and in accordance with findings from Sander *et al.* (2015). Importantly, the percentage of blue light during night work was a little lower than during nights spent at home. The lowest percentage of blue light and highest percentage of red light was observed during winter evenings when light sources are expected to be solely electrical.

In our study, indoor and in particular night workers were exposed substantially longer to light intensities >1000 lux and 2500 lux on days off work compared with work days, in line with other studies of indoor workers (Koller *et al.*, 1993; aan het Rot *et al.*, 2008; Crowley *et al.*, 2015), but not night workers (Koller *et al.*, 1993; Borugian *et al.*, 2005).

We decided on a nocturnal threshold for melatonin suppression and circadian phase shift of 80 lux as suggested by Zeitzer *et al.* (2000). Rea, Figueiro and colleagues have designed a model consistent with data obtained from psychophysics, electrophysiology, and neuroanatomy that predicts acute melatonin suppression following nocturnal exposure to incandescent light (Rea *et al.*, 2005; Figueiro *et al.*, 2006). According to this model, 1 h light exposure of 30 lux will result in 11% melatonin suppression. However, there is only limited human data that verify these effects at low light intensities (Rea and Figueiro, 2013).

Increased occurrence of breast cancer and other cancers have been observed among night workers in several studies (Yuan *et al.*, 2018) but not in resent follow-up studies (Travis *et al.*, 2016; Vistisen *et al.*, 2017). The association has been explained by melatonin suppression and circadian phase disturbance due to light exposure at night (Straif *et al.*, 2007). Our findings suggest that the average night worker was exposed to light levels during night with little effect on melatonin level and circadian rhythm. This is reassuring. It should, however, be mentioned that night workers were exposed to lower levels of light during daylight hours and thus experienced a blunted circadian pattern of light and dark which may affect circadian adjustment (Dumont and Beaulieu, 2007).

The limited exposure to light >1000 lux during daytime that we observed for indoor workers may affect general well-being, mood, vitality, and learning abilities. aan het Rot *et al.* (2008) found that exposure to light >1000 lux for > ~20 min was associated with better mood, less quarrelsome, and more agreeable behavior. However, no association between duration of exposure to light >1000 lux and mood has also been reported (Hubalek *et al.*, 2010).

Nonseasonal depression can be treated with 2-h light therapy >2500 lux applied in the morning (Tuunainen *et al.*, 2004), and a 1-h outdoor morning walk may improve SAD symptoms (Wirz-Justice *et al.*, 1996). In winter, very few participants in our study reached an exposure intensity of 2500 lux, but even during summer work days only half of the outdoor workers spent 100 min or more >2500 lux.

Strengths and limitations

Wearing an Actiwatch may be impractical and cause discomfort and complete compliance with the protocol was not expected. Participants were not observed during follow-up but instructed to record when they did not wear the Actiwatch. In addition, we used actigraphy recordings to identify measurements that we assumed did not represent actual personal light exposure. Only ~12% of the light recordings did not comply with the protocol for either reason. In our opinion, this was a small number given that this was a field study with data collection 24/7. Omitting these measurements should have improved study validity.

Light measurements were calibrated to account for variation between the Actiwatches and against a cosine corrected photometer with a spectral sensitivity that closely relates to the luminosity function V (λ) (Markvart *et al.*, 2015) and this should also have contributed to the study validity.

Light measurements were conducted by Actiwatches placed at the upper arm and may not represent the relevant retinal light exposure accurately because light intensities are shown to be lower when measured at the wrist than at the eye (Figueiro *et al.*, 2013). We are not aware of studies evaluating the effect of wearing the light recorder at the upper arm. Moreover, light measurements depend on arm movements and positions. The measured light may differ from actual light intensities during certain light conditions because of the mismatch between the spatial and spectral sensitivity of the Actiwatch towards a standard classified illuminance sensor (Price *et al.*, 2012; Figueiro *et al.*, 2013).

Many of the outdoor and night workers were not working permanent night or outdoor shifts but were alternating with indoor and day shifts. For these participants, we left out the latter days. To assess the average long-term light exposure for outdoor and night workers one therefore has to account for the frequency of such shifts.

We included participants from a wider range of occupations than in earlier similar field studies and this should have improved the generalizability. However, still a limited number of occupations were represented and our findings may not be representative for the general Danish labor market or the labor market of other regions with a different occupational profile.

Women constituted a high proportion of participants and this probably reflected the recruitment procedure because we approached more occupations with female dominance, such as child care workers, hospital employees, teachers, and social workers but may also represent more willingness of women to participate. If men and women have different light related behaviors this may have confounded our results.

Time of the day and season are the predominant predictors of light intensity and for that reason analyses were stratified by these two factors that should not have confounded our findings.

Participants signed up following advertisements with employers or requests by foremen or managers and may not represent the light exposure of the source population but it is hard to say if this may have over or underestimated the true light levels.

The distributions of light intensity and duration above the different thresholds were not normally distributed. Log transformation improved this to some extent but residuals of the regression models were not normally distributed. Thus, readers should not put too much emphasis on the exact numbers presented.

To our knowledge, this study is the largest field study of this kind to date and precision was not of major concern.

The study was carried out in Denmark (55–56°N) and this undoubtedly affects the generalizability to other locations not only because of the seasonal differences in length of the day, the angle of the sun, and the climate, but also because people living at higher latitudes may seek direct sunlight more than people living at lower latitudes or other behavioral factors that we were not able to address.

Conclusion

The night workers of this study were during night hours on average exposed to light intensities >80 lux expected to suppress melatonin for a limited time. The indoor workers were exposed to light intensities during daylight hours that may reduce general well-being and mood, especially during winter. Outdoor workers were during summer daylight hours exposed to light levels comparable to those used for the treatment of depression.

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