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A Week in the Life of Full-Time Office Workers: Work Day and Weekend Light Exposure in Summer and Winter

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Abstract

Little is known about the light exposure in full-time office workers, who spend much of their workdays indoors. We examined the 24-hour light exposure patterns of 14 full-time office workers during a week in summer, and assessed their dim light melatonin onset (DLMO, a marker of circadian timing) at the end of the working week. Six workers repeated the study in winter. Season had little impact on the workers' schedules, as the timing of sleep, commute, and work did not vary by more than 30 minutes in the summer and winter. In both seasons, workers received significantly more morning light on workdays than weekends, due to earlier wake times and the morning commute. Evening light in the two hours before bedtime was consistently dim. The timing of the DLMO did not vary between season, and by the end of the working week, the workers slept at a normal circadian phase.

Keywords

circadian; light exposure; full-time office worker

1. Introduction

The circadian system regulates many physiological and behavioral rhythms over the course of about one day. The daily timing of sleep and wake, for example, is largely influenced by the circadian system, though voluntary human behavior can override this internal time-keeping system. On average, the central circadian clock in humans has an endogenous period of ~24.2 h (Burgess and Eastman, 2008; Czeisler et al., 1999) and therefore requires daily phase advances (shifts earlier in time) to remain synchronized to the external 24-h day. Light in the evening causes the clock to shift rhythms later (phase delay) and light in the morning causes the clock to shift rhythms earlier (phase advance) (Czeisler et al., 1989; Khalsa et al., 2003). Thus, morning light is essential for the daily corrective phase advances,

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while evening light can exacerbate the clock's endogenous tendency to drift later and promotes circadian misalignment. Many people chronically experience such circadian misalignment when their circadian clock promotes later sleep, but they are required to wake prematurely to an alarm clock to meet their social obligations, such as work (Roenneberg et al., 2012; Wittmann et al., 2006). This “social jetlag” is associated with reduced alertness and performance (Burgess et al., 2012; Taylor et al., 2008; Yang and Spielman, 2001; Yang et al., 2001), greater use of alcohol, nicotine and caffeine, and an increased risk for depression and obesity (Levandovski et al., 2011; Roenneberg et al., 2012; Wittmann et al., 2006).

Full-time office workers are at high risk for social jetlag given their need to get up early in the morning to get to work, and their reduced exposure to the external light-dark cycle while they work ~8 hours indoors during the workday. Several previous studies have measured 24-hour light exposure in healthy adults but the samples were of mixed (e.g., students, unemployed, part-time workers, full-time workers, retired) or unreported employment status (Cole et al., 1995; Hebert et al., 1998; Jean-Louis et al., 2000; Kawinska et al., 2005; Thorne et al., 2009). Others measured 24-hour light exposure in participants who slept according to fixed sleep times (Emens et al., 2009; Goulet et al., 2007; Scheuermaier et al., 2010). One study measured light exposure during a work week in daytime hospital workers, and reported lower light exposure at work (< 500 lux) (Heil and Mathis, 2002). Unfortunately, however, they did not examine light levels by time of day, and their photosensor saturated at a relatively low 2500 lux. Thus, little is known about the 24-hour light exposure patterns of full-time office workers during a typical week when they are free to sleep and wake as they choose. The only opportunities for being outside and exposed to sunlight may be the commute to and from work, and perhaps during a lunch break. Limited exposure to the external light-dark cycle may be further exacerbated in winter when day length is shorter (Cole et al., 1995; Hebert et al., 1998; Jean-Louis et al., 2000; Thorne et al., 2009), and colder temperatures lead people to spend more time inside (Cole et al., 1995).

Thus, the aim of the current study was to describe the 24-hour light exposure patterns of full-time office workers over the course of a typical week during the summer months, when outdoor light exposure is expected to be optimal due to a long day length and warm climate in Chicago IL. A second aim was to compare 24-hour light exposure patterns of a subset of these full-time office workers again in the winter. Sleep/wake behavior, morning commute time, and evening activities were also examined, as a means to determine potential causes of alterations in light exposure.

2. Material and Methods

2.1. Participants

Fourteen full-time office workers (4 males) ages 20 to 39 years (mean $\pm$ SD = 28 $\pm$ 5 years) completed the study between August 1 and September 12, 2012 (summer) in Chicago, USA at 41° 88' N latitude. Participants self-reported their race as White/Caucasian (n=10), Black/African American (n=2), or multiracial (n=1), one was unknown, and most identified as non-Hispanic (n=13). Six of the 14 workers (2 males, 4 females; 4 Caucasian, 2 African

American; mean $\pm$ SD age = 30 ± 7 years) repeated the study between January 30 and March 13, 2013 (winter).

Participants were non-smokers, and consumed moderate caffeine (< 300 mg/day) and alcohol (< 2 standard drinks/day) doses. All participants passed urine drug screens, reported no medical, psychiatric, or sleep disorders, and were medication free except for 4 women who were taking oral contraceptives. Body mass indices ranged from 20.9 to 34.2 kg/m^2 (mean $\pm$ SD = $26.6 \pm 4.4 \text{ kg/m}^2$). Participants did not use corrective lenses (glasses or contact lenses), were not color blind according to the Ishihara test for color blindness, and reported no corrective eye surgery (e.g., LASIK).

Participants were working full-time in the same office for at least one month before beginning the study. Participants worked on weekdays (Monday through Friday), and did not work on weekends. Reported work start times ranged from 7:30 to 9:30 (mean $\pm$ SD = $8:28 \pm 00:34$) and end times from 16:30 to 18:00 (mean $\pm$ SD = $17:06 \pm 00:28$). Participants reported no night shift work in the month before the study start and no travel across time zones in the month before the study start. The Rush University Medical Center Institutional Review Board approved the study protocol, and therefore, the study was performed in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki. Each participant provided written informed consent before study participation, and received monetary compensation for participation.

2.2. Protocol

Throughout a 10-day protocol, participants were instructed to keep their usual sleep schedule and daytime work schedule during the summer. On day 2 (Thursday) of the study, participants visited the laboratory so that we could review their data and provide any feedback or corrections. After this visit, participants did not come back to the laboratory for the next 7 days (5 workdays and 2 weekend days) so as not to disturb their normal weekly routine. On day 10 (Friday), participants completed a circadian phase assessment in the laboratory. Two to 3 participants completed the study at the same time. A subset of participants repeated the same 10-day protocol during the winter. One female participant changed jobs between summer and winter assessments; however, her typical work schedule was similar between seasons (summer: 8:30–17:00; winter: 8:45–17:00).

2.3. Behavioral sleep/wake and ambient light exposure

Participants wore two actigraphs throughout the study. One actigraph was worn on their non-dominant wrist (Actiwatch-L, Philips Respironics, Inc. Bend OR) to monitor sleep/wake behavior. Data were collected in 30-second epochs. Participants documented their bedtime and wake times, and their activities during the 4 hours before bedtime each day, which guided actigraphic analysis of sleep and wake. Wrist activity data were analyzed using Actiware 5.7 (Philips Respironics, Bend OR) using the immobile minutes sleep interval detection algorithm (10 mins of immobile minutes defined sleep onset and sleep end) and a medium wake threshold. Each sleep episode (including any reported naps) was scored beginning at participant-reported bedtime until reported wake-up time. If discrepancies between reported sleep times and the actogram emerged, the authors inspected

these data together to determine the scoring interval. The following variables were extracted: sleep onset time, sleep end time, and total sleep time. The wrist actigraph failed on a total of 17 nights (10.6% of total number of nights analyzed). Reported sleep onset and wake-up time from daily logs were used instead of actigraphic sleep estimates in these cases when it was not available.

A second actigraph with photosensor (Actiwatch Spectrum, Philips Respironics, Inc. Bend OR) was worn around the neck (closer to the eye than the wrist) like a medallion to measure 24-hour ambient light exposure (Burgess and Eastman, 2004, 2006). Data were collected in 30-second epochs. Participants were instructed to remove the photosensor around the neck for showers or baths and while sleeping, but to keep the photosensor facing outward in the same room. Times at which participants removed the photosensor were documented daily. Activity on the photosensor around the neck was inspected using Actiware 5.7 to ensure participants wore the photosensor, and that they accurately documented when the photosensor was not being worn. Ambient light measured during times when the photosensor was not being worn during waking hours was omitted from the dataset. The percent of epochs removed for each participant ranged from 1.9% to 11.7% (mean $\pm$ SD = 5.5% $\pm$ 3.2%) in the summer and 1.8% to 11.7% (mean $\pm$ SD = 5.8% $\pm$ 3.6%) in the winter.

White (broad spectrum) light data collected after the laboratory visit on day 2 until the start of the circadian phase assessment on day 10 were included in the analysis. Illuminance was measured in lux (SI unit for illuminance). Ambient light from sleep onset to sleep end (measured from wrist actigraphy) was recoded as 0 lux. If participants wore sunglasses, they recorded sunglasses on and off times on a daily log, and pressed an event marker on the photosensor when the sunglasses were put on and taken off. The percent of light transmitted through each participant's personal sunglasses was measured in the laboratory, and then used to correct the light data. The light data were averaged into 30-minute bins according to 24-hour clock time separately for workdays and weekend days. Data were also averaged into 30-minute bins relative to actigraphically estimated sleep times. The minimum daily wake duration in the current sample was 11 h 29 minutes; therefore, we examined light in the 5.5 hours after wake time and the 5.5 hours before sleep start time separately for weekends and weekdays. Data were base 10 log-transformed ($\text{Log}_{10}(\text{white light lux} + 1)$) (Burgess and Eastman, 2006; Burgess and Molina, in press; Emens et al., 2009).

Some context is necessary to interpret light level findings in this study. The light level at twilight is about 3 lux and at sunrise/sunset is about 400 lux under a clear sky. Outdoor light levels during the daytime are greater than 1000 lux, and can reach more than 100,000 lux on a bright sunny day. By contrast, indoor lighting is not as bright as the outdoors; light levels in the home are typically less than 50 lux (Burgess and Eastman, 2004) and light levels in office environments can average from about 300 to 1000 lux depending on whether there are windows in the office (Boubekri et al., 2014) and the proximity of the work space to windows (Kozaki et al., 2012).

Participants emailed laboratory staff daily when they arrived at work to report: (1) clock time they left home to go to work; (2) clock time they arrived at work; (3) whether they

stopped on their way to work; and (4) the method of transportation to get to work. Morning commute time each day was computed as amount of time between leaving home and arriving to work (Christian, 2012). Participants also documented daily whether they left work for a lunch break as this could increase their exposure to outdoor light.

2.4 Circadian phase assessments

Participants completed a circadian phase assessment in dim light in the laboratory to determine their dim light melatonin onset (DLMO), a reliable phase marker of the circadian system (Klerman et al., 2002; Lewy et al., 1999). Methodological details of the phase assessments have been previously described (Burgess and Eastman, 2004, 2006). Briefly, participants remained awake and seated in dim light (< 5 lux at the eye in direction of gaze) and provided a saliva sample every 30 minutes beginning 7 hours before to 3 hours after their average bedtime. Participants were not permitted to consume alcohol or caffeine in the 24 hours before each phase assessment and were breathalyzed when they arrived at the laboratory. Non-steroidal anti-inflammatory drugs and recreational drugs were not permitted throughout the study.

Saliva samples were centrifuged, frozen immediately, and later assayed for melatonin using direct radioimmunoassay (RIA) by Solidphase, Inc (Portland, ME) using commercially available kits (ALPCO, Inc). Each individual's samples were analyzed in the same batch. The first non-zero standard of this assay was 0.5 pg/ml. Intra-assay coefficients of variation for low (daytime), medium (evening), and high (nighttime) levels of salivary melatonin are 20.1%, 4.1%, and 4.8%, respectively. The inter-assay coefficients of variation for low, medium, and high levels of salivary melatonin are 16.7%, 6.6%, and 8.4%, respectively. A DLMO was computed for each participant. The melatonin threshold was the mean plus two standard deviations of three low consecutive daytime salivary melatonin values (Voultsios et al., 1997). DLMO was defined as the clock time when melatonin concentration exceeded this threshold and was computed using linear interpolation between the melatonin samples below and above the threshold.

2.5 Statistical analysis

Light levels were compared between workdays and weekend days during the summer for the entire sample (n=14) and for the subsample that completed the study again in the winter (n=6). Light levels were compared between summer and winter using the subsample (n=6) who completed the study during both seasons. First, means and 95% confidence intervals for log-transformed light data were plotted by 24-hour clock time. Post-hoc paired t-tests were computed for any 30-minute bins in which light distributions diverged. The same analytic approach was used to examine light exposure in the 5.5 h before sleep onset and in the 5.5 h after wake time. Given this multiple testing approach, differences across successive time points were considered to be more meaningful than a single time point difference.

To gain a better understanding of light exposure timing and duration, the first clock time, last clock time, and total minutes above 10, 180, 550, and 1000 lux were compared between weekend days and workdays and between seasons. These thresholds were chosen because previous studies have shown phase advances in response to 180 lux (Boivin et al., 1996) and

saturation of phase shift responses to 550 lux, in participants sensitized to light (Zeitler et al., 2000). The 10 lux and 1000 lux thresholds have been used in previous studies (Espiritu et al., 1994; Hebert et al., 1998; Kawinska et al., 2005; Wright et al., 2013) to define light brighter than dim room light and light that is likely outdoor light, respectively. A paired t-test was used to compare weekend and workday differences in these outcome measures for the main summer sample. A 2 (day type: workday versus weekend day)-by-2 (season: winter versus summer) repeated measures analysis of variance was computed to examine seasonal differences and day type-by-season interactions within the sub-sample that completed the protocol in both winter and summer. A paired t-test was used to test if the DLMO changed between summer and winter.

3. Results

3.1. Daily schedule of full-time office workers

Figure 1 illustrates the average workday and weekend day of the full-time office workers in this study, in summer and winter. In the summer, the workers arrived home for the last time on average 2.8 hours before sleep onset on workdays, which was just before civil twilight, suggesting that most of their light exposure after this time was due to artificial indoor lighting. The most common activity in the hour before bed was watching TV. Average sleep onset and sleep end were $23:22 \pm 00:41$ and $6:43 \pm 00:46$ respectively, and average total sleep time was $398 (\pm 28)$ minutes. All participants woke after civil twilight in the summer. Approximately 1.5 hours after waking, the workers began their commute between 6:26 and 9:01 (mean $\pm$ SD = $8:06 \pm 00:51$), and arrived to work between 7:40 and 10:46 (mean $\pm$ SD = $9:01 \pm 00:58$). Morning commute times ranged from 11 mins to 128 mins (mean $\pm$ SD = 54 ± 30 mins). The longest commute times and latest work arrival times were due to one worker who dropped her children off to school each day before work. The majority of participants commuted to work via public transportation (72%). Of the 5 workdays examined, 12 of the 14 workers went outside of the office for a lunch break at $12:29 \pm 00:55$ and returned at $13:21 \pm 1:02$. A lunch break, however, was not necessarily taken every day; 3 of the 12 took a lunch break all 5 workdays, 4 took a lunch break on 3 or 4 workdays, and 5 took a break on only 1 or 2 days. Prior to the study start, workers reported on average leaving work at $17:06 \pm 00:28$. On the weekend, the participants arrived home for the last time at a later clock time, but at a similar 2.7 hours before sleep onset, and well after civil twilight. Watching TV remained the most common activity in the hour before bed on weekends. On the weekend, participants had later sleep start times ($00:29 \pm 01:20$) and later sleep end times ($08:20 \pm 01:22$) (both t-tests $p < 0.001$). Total sleep time on weekend nights did not significantly differ from work nights (422 ± 68 minutes).

As shown in Figure 1, the transition to winter had little impact on the workday and weekend schedules of these full-time office workers. Sleep start and end times, total sleep time, commute start, work start, lunch break and work end times remained consistent with their summer daily schedule, occurring on average within 30 minutes of their summer schedule. Participants still woke on weekdays after civil twilight. On average, participants arrived home for the last time 51 minutes earlier on winter workdays compared to summer workdays, though this was only a trend ($p = .056$). Participants arrived home for the last time

at about the same time on the weekends in winter and in summer ($p=.25$). Watching TV remained the most common activity in the hour before bed on winter weekdays and weekends.

3.2. Ambient light by 24-hour clock time: workday versus weekend

Figure 2 illustrates 24-hour light exposure patterns on workdays versus weekends during the summer and winter. During the summer, workers received more morning light on workdays versus weekend days as they woke earlier and commuted to work. Thus light exposure was greater at 6:30, 7:00, 7:30, 8:00, and 9:00. As expected, Table 1 illustrates that morning light exposure exceeded 10 lux about 1.5 hour earlier on workdays, again due to the earlier wake time. In the summer evenings, participants received more light between 21:00 to 22:30 on work days than on weekends. This may be due to participants being home at this time on workdays, exposed to indoor lighting, but more likely to be outside (after civil twilight) in warm temperatures at this time on weekends.

In the winter, workers also received more morning light on workdays as they woke earlier and commuted to work. Thus light exposure was greater at 6:30, 7:00, 7:30, 8:00, and 8:30. Table 1 illustrates that morning light exposure exceeded 10 lux about 2.5 hour later on weekends, likely due to the later wake time. In winter, there were no differences in evening light exposure between work days and weekends, as cold temperatures likely kept participants inside as much as possible, exposed to indoor lighting, whether at home or outside of the home.

3.3. Ambient light by 24-hour clock time: summer versus winter

Figure 3 illustrates 24-hour light patterns on workdays and weekends for the subsample that completed the study during the summer and then repeated the study during the winter. Notably, sunglasses use was higher in the summer than winter: of the six workers who completed the study during summer and winter, 4/6 wore sunglasses during the summer only, 1/4 wore sunglasses during both seasons, and 1 did not wear sunglasses during either season. Season did not impact morning light exposure on work days. Participants left work about an hour before civil twilight in winter, but more than 3 hours before civil twilight in summer (Figure 1). Therefore, participants received more light in the early evening on workdays (17:00, 17:30, 18:00, and 18:30) in the summer than in the winter. Additionally, the last clock time of light >550 lux occurred over 2.5 h earlier on workdays in the winter than in the summer (Table 1). Season also impacted evening light exposure on weekends (Figure 3). Participants received more light in the early evening (18:00, 18:30) in summer, probably from outdoor activities occurring before civil twilight, but received more light later in the evening (22:00, 22:30) in winter, as colder temperatures kept them inside exposed to indoor lighting. There was no apparent increase in light exposure during lunch breaks on workdays in both seasons, perhaps because lunch breaks outside were not regularly taken. Winter also impacted the overall amount of light exposure, as on both workdays and weekend, the number of minutes of light >180 lux was 138–148 minutes less in winter than in summer.

3.4 Ambient light relative to sleep: weekdays and weekends

We examined the light levels in the 5.5 hours before actigraphically estimated sleep onset time and in the 5.5 hours after actigraphically estimated wake-up time to gain a better understanding of light exposure during times when the circadian system is most responsive to light (Figure 4). Ambient light before sleep onset slowly decreased on workdays and weekends during the summer, and light exposure was greater on workdays (earlier clock time) compared to weekend days (later clock time) for much of the later evening. In the 4.5 to 5.5 h before sleep onset in the summer, median light levels were > 100 lux (range: 116 – 380 lux) on workdays, whereas on weekends median light levels were < 100 lux (range: 35 – 80 lux). This is explained by bedtime occurring about 1.5 hours later on the weekend versus workdays. These differences disappeared in winter where light levels were similar before bedtime on weekdays and weekends (median light levels < 43 lux). Overall, after wake light intensity was higher in the summer than the winter on both workdays and weekends. A trend for greater light exposure on summer workdays compared to weekends emerged at 120 minutes after waking ($p=0.06$).

3.5 Circadian timing: phase and phase relationships to sleep and light exposure

On average, the DLMO occurred at 20:07 during the summer, which was 3.3 ± 0.8 h before sleep onset, 10.6 ± 0.9 h before sleep end time, 11.3 ± 0.7 h before light > 180 lux for the first time, and 11.7 ± 0.8 h before light > 550 lux for the first time. Interestingly, the DLMO was not significantly different between summer and winter, suggesting that the fixed daily work schedule stabilized circadian timing, regardless of the significant seasonal differences in the external photoperiod. We computed post-hoc Pearson correlation coefficients to test associations between the DLMO and the first clock time, last clock time, and total duration at which light levels were greater than 10, 180, 550, and 1000 lux in the main summer sample. The DLMO was later if the first exposure to 10 lux ($r = 0.55$, $p = 0.04$) and 180 lux ($r = 0.61$, $p = 0.02$) were also later. Trends were seen for the 550 lux ($r = 0.51$, $p = 0.06$) and 1000 lux ($r = 0.52$, $p = 0.06$) thresholds. Similarly, the DLMO was later if the last daily exposure to 180 lux was also later ($r = 0.77$, $p = 0.001$). A similar trend was seen for the 10 lux threshold ($r = .49$, $p = .08$), but the last daily exposure to 550 lux and 1000 lux were not associated with the DLMO. Total duration of time exposed to light at any level did not correlate with the DLMO. Duration of workday commute also did not correlate with the timing of the DLMO ($r = -.21$, $p > 0.05$), even when partialling out commute start time ($r = -.23$, $p > 0.05$).

4. Discussion/Conclusion

We examined the 24-hour light exposure patterns of full-time office workers over the course of a typical week during the summer, and re-examined light exposure patterns in a subsample of workers who repeated the study in the winter. We found that the workers' daily schedules were consistent between summer and winter (Figure 1), whereas previous studies with samples of mixed employment status reported later sleep/wake timing in the winter as compared to the summer (Hebert et al., 1998; Honma et al., 1992; Kohsaka et al., 1992). Our finding suggests that there is less variability in the daily schedules of full-time office workers than other employment groups, and the lives of full-time office workers may be

more driven by the social clock time and not by sun time. Workers consistently received more morning light on workdays than weekends, in both summer and winter (Figure 2), which was largely due to the earlier wake times on workdays compared to weekend days and the morning commute to work (Figure 1). The average morning commute time was almost an hour in our sample, which is longer than the 35 minutes reported in other large American cities (U.S. Census Bureau et al., 2013), and likely longer in part due to one worker dropping her kids off at school on her way to work. Workers received ~2.5 hours of bright outdoor light (>1,000 lux) on summer workdays, but only about half of this on winter workdays (Table 1). This is comparable with the 2.4–2.6 hours of bright light per day reported in previous studies of healthy adults during the summer at northern latitudes (44° 1'–45° 31' N)(Cole et al., 1995; Hebert et al., 1998). Unlike these previous studies however, we found over an hour of bright light on winter workdays, whereas they reported only 0.4 hours of bright light per day in the winter. Interestingly, our data are similar to more recent data (2010) from a large central European sample, in which people reported spending ~2.2 hours outdoors in the summer and ~1.9 hours in the winter (Roenneberg et al., 2012). Notably, these durations of time spent outside progressively reduced over the previous 8 years, suggesting people are increasingly obtaining less and less outdoor light. On the weekend, the workers in our study received 2.7–3.3 hours of bright light in the summer and again only about half of this on the winter weekend, reflecting their increased opportunity to go outside on the weekend, but reduced exposure to sunlight due to a short photoperiod and colder temperatures in the winter.

During the summer and winter workdays, there was no clear increase in light exposure during lunch breaks, as these were not consistently taken each day. Workers received more early evening light on both workdays and weekends in the summer (Figure 3), and the last moderate to bright light exposure (> 550 lux and > 1000 lux) occurred 2 to 2.5 hours later on summer days compared to winter days (Table 1). This is likely due to the longer photoperiod and the opportunity to spend time outside in the warm evenings (Cole et al., 1995). After civil twilight in summer, however, the workers received more late evening light (most likely from indoor artificial lighting) on workdays than weekends, likely because of their earlier arrival time home on weekdays (Figures 1 and 2). Similarly, workers received more late evening light (at ~22:00) on the winter weekends than summer weekends. This may be because of the necessity to spend more time inside, out of the winter cold and exposed to artificial light (~40 lux) during the winter, whereas the warm temperatures of summer may have allowed these young adults to stay outside after sunset and exposed to dim light (< 10 lux) or darkness (Figure 3).

In the two hours before sleep onset, light exposure was consistently low in both summer and winter and on workdays and weekends (between ~5–20 lux) (Figure 4). This is likely because this time interval occurred well after civil twilight, workers were home in indoor lighting, and the most common activity prior to bed was watching TV. These light levels are similar to those reported in the few hours before bedtime in previous field studies (Burgess and Eastman, 2004; Scheuermaier et al., 2010). In the two hours after wake time, light exposure was higher in summer (>1,000 lux), but otherwise not notably different between work days and weekends, as workers consistently woke after civil twilight on work and weekend days in both summer and winter.

The observed delay in sleep times on work-free versus work days is commonly observed (Monk et al., 2000; National, 2005; Roenneberg et al., 2003), can cause circadian phase delays of up to 1 hour (Crowley and Carskadon, 2010; Taylor et al., 2008; Yang et al., 2001), and may take several work days to overcome (Taylor et al., 2008). In this study, despite some differences in light exposure between seasons, the timing of the DLMO at the end of the working week did not differ between summer and winter. Other studies have reported a delayed melatonin phase in winter compared to summer, but again these were studies of people with presumably more flexible schedules than full-time office workers (Honma et al., 1992; Illnerova et al., 1985; Kennaway and Royle, 1986). The timing of the DLMO significantly correlated with the first exposure to 10 lux, which occurred shortly after waking indoors. Earlier exposure to morning light and leaving the house earlier was associated with an earlier DLMO. The total duration of the morning commute, and overall amount of light exposure, did not correlate with the DLMO. This result suggests that the significant changes in photoperiod between seasons had less of an impact on the timing of the DLMO at the end of the week, than the perceived light dark cycle created from a regular weekly schedule. It also suggests that the timing of light is critical in determining the timing of the DLMO and not the overall amount of bright light exposure per se. Morning light exposure between summer and winter workdays was similar, possibly due to the increased use of sunglasses in the summer. While workers received more early evening light exposure in the summer than winter (Figure 3A), this early evening light occurred at a time when the system has reduced sensitivity to light (~ 2 to 4 hours before the average DLMO) (St Hilaire et al., 2012). Thus the similar perceived light dark cycles between summer and winter workdays likely led to the stable timing of the DLMO between seasons. The timing of the DLMO relative to sleep onset (~3 h) was similar to previous studies of healthy adults (Burgess and Fogg, 2008), and suggests that by the end of the working week these full-time office workers were well adjusted to their work day sleep schedule, with little circadian misalignment.

There were a number of strengths to this descriptive study of 24-hour ambient light exposure, including an exclusive focus on full-time office workers studied during a full week of 5 workdays and 2 weekend days. Monitoring participants' behavior during this week may have influenced behavior; however, our intentional limited contact with participants during this week likely reduced the risk of workers changing their typical habits. The seasonal differences reported may be underpowered as only 6 workers were able to repeat the study in winter. Thus, future studies with a larger sample size may be needed to confirm these findings. Additionally, this was a repeated measures study and light exposure data in other employment groups were not collected at the same time. Thus we cannot be certain that in the same city in the same season, part-time workers for example would have received more bright light. The study is also limited by the restricted age range and other sociodemographic factors in this sample of full-time office workers. It is unclear, for example, whether these findings would generalize to an older office worker who may hold a more senior position with longer and more or less flexibility in standard work hours. Also, childcare for one worker in this study impacted commute times and work start times. It is unclear whether the daytime routine of a full-time office worker with school-aged children would be as stable when child care may change from school year to summer vacation.

Future studies with a wider age range and greater variability in these types of social factors may be needed to confirm the seasonal stability of daily routines in full-time office workers. Nonetheless, the results from this unique study of 24-hour light exposure in young full-time office workers suggests their stable daily work schedules creates a perceived light-dark cycle that can be similar in summer and winter, resulting in a similar circadian timing in summer and winter.

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Highlights

- Measured 24-h light exposure in full-time office workers in summer & winter weeks
- Consistent workday/weekend schedules and circadian phase between summer & winter
- Morning light exposure was greater on workdays versus weekends in both seasons
- Early evening light exposure was greater in summer versus winter on all days
- In the 2 h before sleep onset, light exposure was consistently low (< 20 lux)

Figure 1.

An average daily schedule for full-time office workers in the current study on work days and weekend days during the summer ($n=14$) and winter ($n=6$). The arrows indicate the timing of the DLMO at the end of the working week. The vertical dashed line represents the average time participants arrived home for the last time. Morning commute times (C), work times, and lunch break times (L) are displayed for workdays only. All times are based on 7 days (5 workdays and 2 weekend days) of data collection, except work end time is based on the average times reported before the study began. Error terms are not included for visual clarity (see text for more detail).

Figure 2.

Twenty-four hour light exposure for full-time workers during the summer (A; $n=14$) and a subset of the sample who repeated the study during the winter (B; $n=6$) on workdays (closed circles) and weekend days (open circles). Each point represents the mean and 95% confidence interval of 30-minute intervals averaged and log-transformed for each participant. The x-axis label is the clock time of when the 30-minute bin began. Data from midnight to 4:00 are double-plotted. Asterisks below clock times indicate the 30-minute intervals in which workdays and weekend days differed ($p < .05$). Gray shading illustrates the earliest and latest civil twilight (and therefore longest photoperiod) when the study was in progress. Civil twilight is the time when the center of the sun is 6 degrees below the horizon, and enough light is available to still see objects.

Figure 3.

Twenty-four hour light exposure patterns on workdays (A) and weekend days (B) for a subset of participants ($n=6$) who completed the study during the summer (open symbols) and repeated the study in the winter (closed symbols). Each point represents the mean and 95% confidence interval of 30-minute intervals averaged and log-transformed for each participant. The x-axis label is the clock time of when the 30-minute bin began. Data from midnight to 4:00 are double-plotted. Asterisks below clock times indicate the 30-minute intervals in which summer and winter days differed ($p < .05$). The earliest and latest civil twilight (and therefore longest photoperiod) is illustrated with gray shading for the winter and by vertical lines for the summer.

Figure 4.

Left: ambient light exposure in the 5.5 hours (330 minutes) before actigraphically estimated sleep onset time on workdays and weekend evenings during the summer (A) and winter (B). Right: ambient light exposure in the 5.5 hours after actigraphically estimated wakeup time on workdays and weekends days during the summer (C) and winter (D). Each point represents the mean and 95% confidence interval of 30-minute intervals relative to sleep times and log-transformed for each participant. Asterisks indicate the 30-minute intervals in which workdays and weekends days differed ($p < .05$). All participants who completed the study during the summer ($n=14$) and the subset of participants ($n=6$) who completed the study again during the winter are included in these graphs.

Table 1

Mean (SD in minutes) timing and duration of light levels above 10, 180, 550, and 1000 lux for the entire sample during the summer (n=14) and for the sample subset (n=6) who completed the study during summer and winter months.

	Summer (n=14)		Summer (n=6)		Winter (n=6)	
	Workday	Weekend	Workday	Weekend	Workday	Weekend
First clock time light level						
10 lux ^a	6:56 (36)	8:28 ^{**} (92)	6:48 (20)	8:29 (112)	6:19 (36)	8:51 (49)
180 lux ^a	7:25 (40)	9:06 ^{**} (100)	7:27 (37)	9:07 (104)	7:22 (38)	9:10 (54)
550 lux ^a	7:48 (36)	9:40 ^{**} (126)	7:46 (37)	10:05 (163)	7:50 (14)	9:47 (94)
1000 lux ^a	7:50 (37)	9:42 ^{**} (125)	7:48 (40)	10:07 (162)	8:08 (29)	10:35 (147)
Last clock time light level						
10 lux	23:25 (48)	00:00 (152)	23:08 (28)	23:34 (134)	23:52 (95)	00:44 (43)
180 lux	19:41 (62)	20:24 (116)	19:10 (48)	19:16 (93)	17:29 (90)	19:07 (213)
550 lux ^b	18:46 (31)	18:31 (111)	18:36 (34)	17:54 (157)	15:55 (95)	16:12 (68)
1000 lux ^c	18:11 (65)	17:33 (101)	18:15 (43)	17:31 (134)	15:55 (89)	15:44 (48)
Minutes light level						
10 lux ^a	891 (78)	643 ^{**} (134)	854 (99)	658 (153)	874 (142)	683 (116)
180 lux ^b	345 (112)	278 (103)	393 (151)	332 (128)	255 (113)	184 (90)
550 lux ^c	191 (96)	191 (88)	216 (129)	234 (117)	121 (66)	114 (82)
1000 lux ^c	134 (84)	160 (79)	149 (119)	198 (100)	73 (40)	82 (83)

^{**} p < .01 when compared to workday

^a day type main effect (p < .05)

^b season main effect (p < .05)

^c trend for season main effect (p = .06)