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Research Article

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Validation of a Light Questionnaire with Real-life Photopic Illuminance Measurements: the Harvard Light Exposure Assessment Questionnaire

Archna Bajaj[1], Bernard Rosner[2], Steven W. Lockley[3,4], and Eva S. Schernhammer[2,4,5]

Abstract

Background: Shift work, which necessitates light exposure at night, is now considered a probable carcinogen. To study the effects of light on chronic diseases like cancer, methods to measure light exposure in large observational studies are needed. We aimed to investigate the validity of self-reported current light exposure.

Methods: We developed a self-administered semiquantitative light questionnaire, the Harvard Light Exposure Assessment (H-LEA) questionnaire, and compared photopic scores derived from this questionnaire with actual photopic and circadian measures obtained from a real-life 7-day light meter application among 132 women (85 rotating night shift workers and 47 day workers) participating in the Nurses' Health Study II.

Results: After adjustment for age, body mass index (BMI), collection day, and night work status, the overall partial Spearman correlation between self-report of light exposure and actual photopic light measurements was 0.72 ($P < 0.001$; Kendall $\tau = 0.57$) and 0.73 ($P < 0.0001$; Kendall $\tau = 0.58$) when correlating circadian light measurements. There were only minimal differences in accuracy of self-report of light exposure and photopic or "circadian" light measurement between day ($r = 0.77$ and 0.78, respectively) and rotating night shift workers ($r = 0.68$ and 0.69, respectively).

Conclusions: The results of this study provide evidence of the criterion validity of self-reported light exposure using the H-LEA questionnaire.

Impact: This questionnaire is a practical method of assessing light exposure in large-scale epidemiologic studies. *Cancer Epidemiol Biomarkers Prev; 20(7); 1341–9. ©2011 AACR.*

Introduction

Environmental lighting powerfully influences the circadian system in humans (1). In 2007, the International Agency for Research on Cancer concluded that shift work involving circadian disruption is "probably carcinogenic" to humans (2). Light exposure at night may increase cancer risk through suppression of melatonin, a hormone intimately linked to the circadian system that shows cancer-protective effects (3), or by disrupting circadian synchrony. Observational studies have consistently associated night work with an increase primarily in breast cancer risk, but more recent work also suggests increased risk of colorectal, endometrial, and prostate cancer (4–13), potentially mediated through the melatonin pathway. Further explorations of the physiologic potential of the association between circadian disruption and disease risk are imperative.

Even though all measurements are prone to error, a light meter is likely to have few correlated errors and thus can be considered the criterion standard for light measurements. While standard light meters can be used, however, paper-based questionnaires are a more practical method of assessing light exposure in large-scale studies. Most prior studies of the reliability and validity of paper-based questionnaires investigated the correlation between self-reported sun exposure and UV radiation (UVR) exposure measured by personal dosimeter to help understand the etiology of sun-related cancers (14–20). Studies were often limited to children and adolescents (15, 17, 20). Study designs described various methods of self-recording with different levels of success, such as recall of sun exposure time over the prior 4 days (15), and recording exposure and activity for periodic intervals (30 or 60 minutes) during daytime hours (14, 16, 18).

Taking a different approach, we investigated (NHS2) the criterion validity of self-reported current light exposure by comparing light measures on the basis of our

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paper-based tool, the Harvard Light Exposure Assessment (H-LEA) questionnaire, and actual light exposure as measured by the Daysimeter [Lighting Research Center (LRC), Rensselaer Polytechnic Institute (RPI), Troy, NY; ref. 21]. The goals of our study were to establish the validity of the H-LEA questionnaire in ranking high versus low levels of light exposure throughout a 24-hour day and to evaluate for differences in validity due to rotating night work practice.

Materials and Methods

Study population

Eligible study participants included women from the NHS2 cohort, which was established in 1989 when 116,609 female nurses between 25 and 42 years old completed a mailed questionnaire. The women have since been followed by mailed questionnaires every 2 years to update exposure and disease information. In 2005, 90,051 participants were still alive and being followed. Volunteer participants for the light measurement validation study were recruited between November 2006 and April 2008, based on predefined eligibility criteria from the overall cohort, as outlined below.

Eligibility and recruitment

Women who, at enrollment, presently worked or had worked rotating night shifts as well as women who never worked night shifts were identified from the NHS2 cohort. Roughly 60% of the nurses in the NHS2 cohort worked rotating night shifts (alternating among day-, afternoon-, evening-, and night shifts; from this point forward the term "night workers" will be used when referring to these rotating night shift workers). Eligible participants were randomly selected from all women within the NHS2 cohort who met the following inclusion/exclusion criteria: returned the 2005 questionnaire; answered the night work questions in the NHS2 questionnaires, from 1989 (baseline) onward; were cancer-free in 2005 (with the exception of nonmelanoma skin cancer); did not report having cardiovascular disease up to 2005; presently (in 2005), did not take any hormonal preparations (oral contraceptives or postmenopausal hormones); were not pregnant or lactating; and were presently (in 2005) in the work force. After these exclusions, 18,044 women remained eligible, and of these, participants were randomly chosen, in 2 waves, using a computer-based random number generator. They were contacted initially by mail, with follow-up by email and telephone (see Fig. 1). The first wave of these invitations was mailed in September 2006 to 720 participants. As the majority of participants from this first wave were day workers, and the remaining nurses from the first wave who were not contacted were also day workers, a second wave of invitation letters was mailed in November 2007 to collect more night workers who would be willing to participate in the study. These invitation letters were mailed to NHS2 cohort members who met the following inclusion/exclusion criteria: answered the 2007 online questionnaire to determine current night work status; answered the night work questions in the NHS2 questionnaires, from 1989 (baseline) onwards; were cancer-free in 2005 (with the exception of nonmelanoma skin cancer); did not report having cardiovascular disease up to 2005; presently (in 2005) did not take any hormonal preparations (oral contraceptives or postmenopausal hormones); were not pregnant or lactating; answered the question about rotating night work in the 2007 online questionnaire (Since June 2007, how many months have you worked rotating night shifts—none, 1–4 months, . . ., 20+ months) and did not answer with "none"; and were not in the prior selection for the first wave of having a history of night work. To maximize enrollment of night workers, we selected all 242 current night workers who passed all exclusion criteria, were not part of the first wave, and worked at least 15 months of night work between 2005 and 2007. Further details about enrollment from these 1 recruitment waves are offered in Figure 1. Based on our initial target enrollment of 150 women, combining waves 1 and 2, we accrued a total of 148 study participants until the end of the study.

Horne–Ostberg Morningness-Eveningness Questionnaire

Morningness-eveningness preference was assessed with the Horne–Ostberg Morningness-Eveningness Questionnaire (MEQ; ref. 22), a 19-item questionnaire with a total score ranging from 16 to 86, previously used extensively in adults and adolescents (23–26). A higher score is indicative of morning types, a lower score of evening types. We added the MEQ only halfway through our study; hence we obtained MEQ scores to define morningness-eveningness preference only in a subgroup of 88 participants.

Short-wavelength, visible light meter

The Daysimeter was developed by the LRC at RPI, as a personal circadian light exposure and activity meter to measure circadian light–dark and activity–rest patterns (21). It is a self-contained, battery-operated data logger worn as a lightweight headset. It has 2 optical sensors placed near the plane of 1 cornea; the first (photopic) sensor detects optical radiation and closely matches the standard photopic luminous efficiency function; the second (blue light) sensor has an intrinsic long-wavelength response cutoff point at approximately 580 nm together with a UV blocking filter creating a spectral response peaking at approximately 460 nm (It should be noted that the spectrum used to define "circadian" light exposure herein has been modeled from prior data (27, 28) but may be subject to revision based on new data (32) or alternative models (33).). From both the photopic and blue sensors, the Daysimeter stores a light value proportional to the logarithm of the short circuit current of the cell. An accelerometer within the Daysimeter is used to detect the subject's activity by measuring acceleration in both horizontal and vertical directions. The Daysimeter stores

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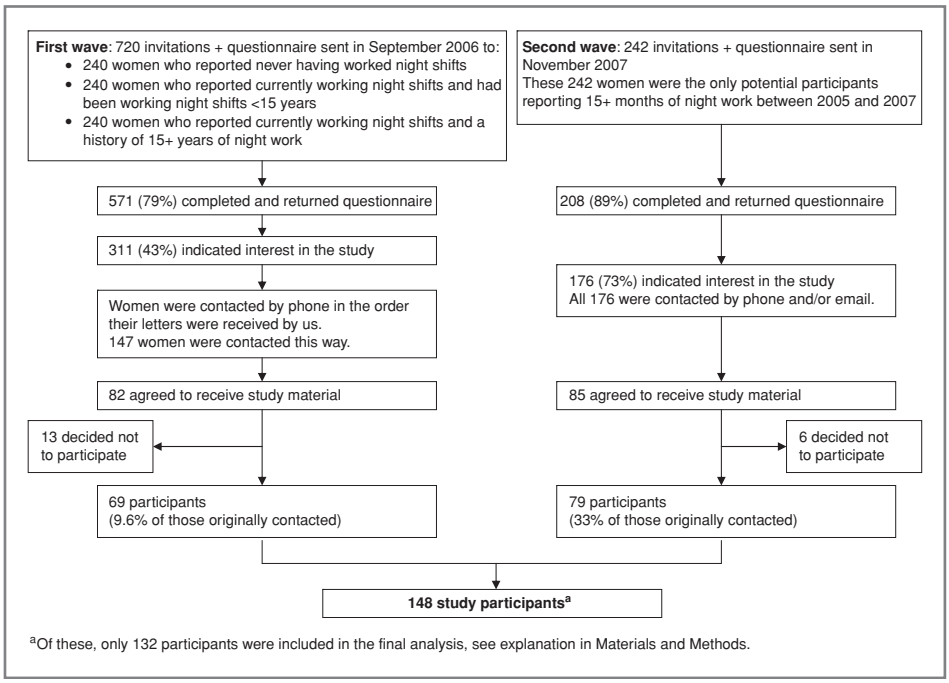

Figure 1. Flow diagram: subject recruitment.

the root mean square value of the acceleration data for each axis over 30 seconds. Current through a reference diode in the Daysimeter is used to approximate the temperature. When data logging, the Daysimeter takes a sequence of 10 readings once a second, spread out over 1 cycle of 60 Hz. The maximum run time of the Daysimeter is 72 days, but in practice, this is limited by battery life to 30 days of active logging. Further technical details about Daysimeter have been described elsewhere (27).

Measures obtained from the Daysimeter were summarized by calculating hourly averages of the 30-second data points of light exposure for each day. Mean photopic illuminance values (lux) were derived from the photopic sensor on the Daysimeter, and mean spectrally weighted illuminance values as a measure for circadian light were obtained from the blue sensor. These circadian light levels were approximated using postprocessing algorithms on the basis of the model of circadian phototransduction by Rea and colleagues (28) and reported in lux, as outlined in more detail in Miller and colleagues (27). Mean corneal illuminance was approximated from the light questionnaire (H-LEA questionnaire) using estimated average illuminance values (lux) for each light source offered on the questionnaire. Values for these approximations were obtained from the LRC at RPI (Table 1). In the H-LEA questionnaire, we assigned "other" light sources a value of 10 lux on the basis of our observation that nurses tended to report in their logs almost exclusively low light levels such as TV in a dark room, or PC, or candle light, as "other" light sources. If a woman noted more than 1 light source for an individual hour on the H-LEA questionnaire, the average illuminance for these light sources was calculated; for example, an "F" (representing fluorescent lamp) and "H" (representing halogen lamp) would amount to 100 + 20 lux = 120/2 lux = 60 lux.

H-LEA questionnaire

The initial version of the H-LEA questionnaire used in the present study was developed by investigators from the Division of Sleep Medicine at Harvard Medical School and subsequently modified for our validation study (see Fig. 2). Light exposure was grouped into 7 types of light sources: halogen lamp, fluorescent lamp, incandescent light, other artificial light source, indoor natural light, sunlight/outdoor natural light, and darkness. Partici-

Table 1. Estimated corneal illuminance provided by the LRC, RPI

Assumed application	Estimated corneal illuminance, lux
D: darkness, suburban night sky	0.2
O: other artificial light source[a]	10
H: halogen lamp residence	20
I: incandescent light residence	20
F: fluorescent lamp office	100
N: natural light (indoors)	200
S: sunlight, natural light (outdoors)	2,000

[a]Mostly low light levels like TV in otherwise dark room, or candle light, or PC (information from diaries).

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During a typical day, describe your exposure to the below specified light sources. Please fill in as applies, for each single day of your 7-day trial, and circle the hours at which you had a meal, like indicated in the example below.[a]

H…Halogen Lamp F…Fluorescent Lamp I…Incandescent Light O…Other Artificial Light Source
N...Natural Light (Indoors) S…Sunlight, Natural Light (Outdoors) D…Darkness

EXAMPLE:

DATE 01/01/2007 ☐ NIGHT SHIFT WORKHOURS FROM ___ TO ___ OR ☐ DAYSHIFT WORKHOURS FROM ___ TO ___ OR ☐ OFF WORK

1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	noon	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am
D	D	D	D	D	D	I	N	F	F	F	S	F	F	F	F	H	F	F	F	I	I	H	H

[a]Mealtime data were collected for other research purposes but not used in this study.

Figure 2. H-LEA questionnaire.

pants were asked to record the light source(s) they were exposed to hourly for 7 consecutive days.

Study design and study procedures

All study materials were mailed to participants. The study was approved by the Harvard School of Public Health and the Brigham and Women's Hospital Human Subjects Committee, and written informed consent was obtained from subjects. Each participant completed the self-administered H-LEA while wearing the Daysimeter for 7 consecutive days and received $100 compensation upon successful completion of the study. Efforts to increase compliance rates included maintaining ample contact and communication with all participants. Investigator-initiated telephone contact was established prior to enrollment. During the 7-day study period, study investigators supplied email and phone number information in case subjects had technical issues or questions related to the rather complex study procedures and materials. If a problem with the Daysimeter arose, a replacement Daysimeter was shipped to the participant as soon as possible, and the study dates were changed in accordance with the study protocol to a new 7-day study period. Study material was accompanied by detailed instructions and thorough study information, including a precaution that study investigators were going to assess the recorded Daysimeter data to check for adherence to study guidelines, and if the participant was determined to be noncompliant, she would not receive the full $100 compensation.

Participants were instructed to wear the Daysimeter for a 7-day period, during all waking hours, except when in water. We did not record whether participants wore sunglasses when outdoors but assumed that outdoor light levels that required them to wear sunglasses would still accurately be reflected by Daysimeter recordings much higher in relation to any measurement obtained from indoor light exposure. To protect the light meter while in, for example, the shower or a swimming pool, they were asked to place the Daysimeter nearby, on a bathroom counter or any surface away from the water, but in the same light environment. They were instructed to keep it next to their bed while sleeping. The Daysimeter is suited for use in working environments including sterile operating rooms.

Exclusions based on faulty data

Of 148 participants, 16 (10.8%) were excluded because of either technical issues or gross noncompliance with wearing the Daysimeter, leaving a total of 132 women for our analyses. Six of the women who were excluded used a particular Daysimeter for which it was detected in hindsight that a technical problem with the photopic sensor rendered the recorded data less useful. For 4 other women, the Daysimeter was either started incorrectly or it malfunctioned such that no data were recorded. It was possible to identify nurses who did not comply with the protocol by using data from the Daysimeter's onboard temperature sensor and accelerometer; room temperature readings, as opposed to elevated temperatures when the Daysimeter is in closer contact with the body, and extended periods of inactivity were certain signs that the nurse did not wear the device when required. On the basis of these criteria, 3 women were excluded because they wore the Daysimeter for less than 3 days, and another 3 women were excluded because their recorded data showed flagrant noncompliance with wearing the Daysimeter over the course of the 7 days, for example, only wearing the Daysimeter for a couple of hours each day. Of the remaining 132 women, 10 others, whose recorded data indicated they were compliant less than 100% of the study time but was not sufficient to conclude they "barely" (i.e., <50% of the time) wore the Daysimeter, were still included for the analysis. A sensitivity analysis was conducted excluding these 10 subjects.

Statistical methods

To assess criterion validity of our paper-based questionnaire (i.e., the degree to which measures obtained from this questionnaire correlate with an established external criterion; ref. 29), we calculated partial Spearman correlation coefficients (with P values) between light values from the H-LEA questionnaire, which were converted into illuminance values (lux) based on estimates

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Table 2. Age and age-standardized characteristics of 132 participants from the NHS2 stratified by work schedule and compared with full cohort of $n = 90,051$ women participating in NHS2 (2005)

Characteristics/lifestyle covariates	Validation subgroup ($n = 132$)		Full NHS2 cohort ($n = 90,051$)	
	Day worker ($n = 47$)	Night worker ($n = 85$)	Never or past night worker ($n = 68,350$)	Current night worker ($n = 21,701$)
Age, mean (SD), y	48.3 (4.4)	47.0 (5.0)[c]	48.5 (4.7)	48.2 (4.7)[d]
BMI, mean (SD), kg/m^2	25.8 (5.3)	28.2 (7.1)[d]	26.3 (7.0)	27.5 (7.2)[d]
Alcohol consumption, mean (SD), g	6.6 (11.2)	3.3 (5.6)[d]	5.7 (9.6)	4.7 (8.5)[d]
Current smokers, %	1.8	2.5[c]	7.3	15.9[d]
Premenopausal, %	54.5	60.3[c]	45.3	43.0
Number of years worked rotating night shifts, mean (SD)	6.9 (6.7)[c]	10.7 (6.0)[c,d]	4.1 (3.7)	5.8 (5.0)[d]
Parity[a], mean (SD)	2.0 (0.9)	2.0 (0.9)	2.1 (0.9)	2.1 (0.9)
Exercise, mean (SD), METs[a]	23.9 (20.9)	25.7 (30.6)	23.2 (29.5)	22.7 (30.5)
Chronotype[b]				
Definite morning type, %	21.3	21.2	NA	NA
Probable morning type, %	46.8	32.9	NA	NA
Probable evening type, %	21.3	27.1	NA	NA
Definite evening type, %	10.6	17.7	NA	NA
HO scores, mean (SD)	53.2 (12.8)	55.2 (9.7)	NA	NA

Abbreviation: MET, metabolic equivalents.

[a]Among parous women only.

[b]Horne–Ostberg (HO) scores only available from a subgroup of women (11 day workers, 71 night workers).

[c]Difference in frequency (χ^2 test) or mean (*t* test) statistically significant between day and night workers, respectively, comparing the validation subgroup with the full cohort, $P < 0.05$.

[d]Difference in frequency (χ^2 test) or mean (*t* test) statistically significant between day and night worker groups, $P < 0.05$.

provided by the LRC, RPI (Table 1) and the 2 light values obtained from the Daysimeter, photopic illuminance (lux) and circadian light (lux), adjusting for nurses' ID. In secondary analyses, we additionally adjusted for day of the 7-day collection and factors that have previously been linked to the circadian system including age, body mass index (BMI; which is associated with rotating night shift work in this cohort; ref. 30), and whether or not participants were current night workers. We also conducted correlation analyses stratified by night work and day work as well as by night time (defined 7:00 PM to 6:59 AM) and day time (defined as 7:00 AM to 6:59 PM). In addition, we quantified the agreement between the 3 light measures using the Kendall tau coefficient, a measure of the degree of correspondence between 2 rankings (31). In subanalyses, we excluded 10 women whose recorded data indicated that they were compliant less than 100% of the study over the course of the 7 days but not so much as to conclude they "barely" wore the Daysimeter. Their exclusion did not change correlations appreciably, and we therefore kept them in our main validation subgroup.

Results

After all exclusions, 132 women remained in our validation sample for a total of 924 days (22,276 hours) of light exposure data collection. Characteristics of the 132 women in the validation study subgroup from within the NHS2 cohort, stratified by day and night work status, are shown in Table 2, along with respective characteristics of the full NHS2 cohort. Overall, 47 of the women in the validation sample were day workers and 85 were night workers. Participants came from 24 states. The 132 women who participated in this study were, for the most part, representative of women participating in the NHS2 cohort in 2005 (90,051 women). Women in the validation group were on an average slightly younger and more likely to be premenopausal, however, reflecting our selection criteria for entry (i.e., they still had to be in the workforce). There were also fewer current smokers among the women who participated in our validation study and they tended to exercise more. On an average, they had worked more years of night work than women from the NHS2 cohort overall. Similarly, when stratifying by day and night work status, night workers tended to be heavier, exercise less, consume less alcohol, and were more likely to currently smoke than were day workers.

Among the subset of 88 women from whom we queried chronotype, night workers were more likely to be definite evening types than were day workers (17.7% vs. 10.6%), but there was no statistically significant difference in mean Horne–Ostberg scores between the 2 groups (mean

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scores 53.2 and 55.2 for day and night workers, respectively).

Light measures obtained from the Daysimeter and H-LEA questionnaire were averaged over each hour of a 24-hour day for all participants combined as well as stratified by night work status. These averages of the absolute values ranged from 0.31 to 1,148 lux of photopic illuminance; from 0.24 to 1,375 lux of circadian light; and from 2.2 to 504 lux for corneal illuminance as derived from the H-LEA questionnaire. When graphing these data (Fig. 3), relative photopic illuminance and circadian light values closely resembled each other and appeared to be well approximated by the estimates derived from the H-LEA questionnaire (Fig. 2).

The close approximation of the Daysimeter values by the H-LEA questionnaire in Figure 3 was reflected in an overall partial Spearman correlation coefficient of $r = 0.72$ after adjusting for age, BMI, day of the 7-day collection, and night work status ($P < 0.001$; Kendall $\tau = 0.57$) for the correlation between H-LEA questionnaire estimates and photopic illuminance, and an $r = 0.73$ ($P < 0.0001$; Kendall $\tau = 0.58$) for the correlation between the H-LEA questionnaire and circadian light if taking the average across all 7 days (Table 3). Crude partial correlation coefficients were very similar to those additionally adjusted for age, BMI, day of collection, and night work status. The overall positive correlations were only slightly weaker among night workers than among day workers (e.g., for photopic illuminance, $r = 0.77$ for day workers and $r = 0.68$ for night workers; all $P < 0.0001$). Moreover, strength of correlations between the individual days of the 7-day validation study did not vary appreciably (Table 3).

When defining daytime as the time between 7:00 AM and 6:59 PM and nighttime as the time between 7:00 PM and 6:59 AM, Spearman rank correlations between light measures obtained from the H-LEA and circadian light measures from the Daysimeter among all women combined were 0.42 ($P < 0.001$) during daytime hours and 0.78 ($P < 0.001$) during nighttime hours. Among day workers, these correlations were 0.38 and 0.74; and among night workers, 0.44 and 0.80, respectively (all $P < 0.001$).

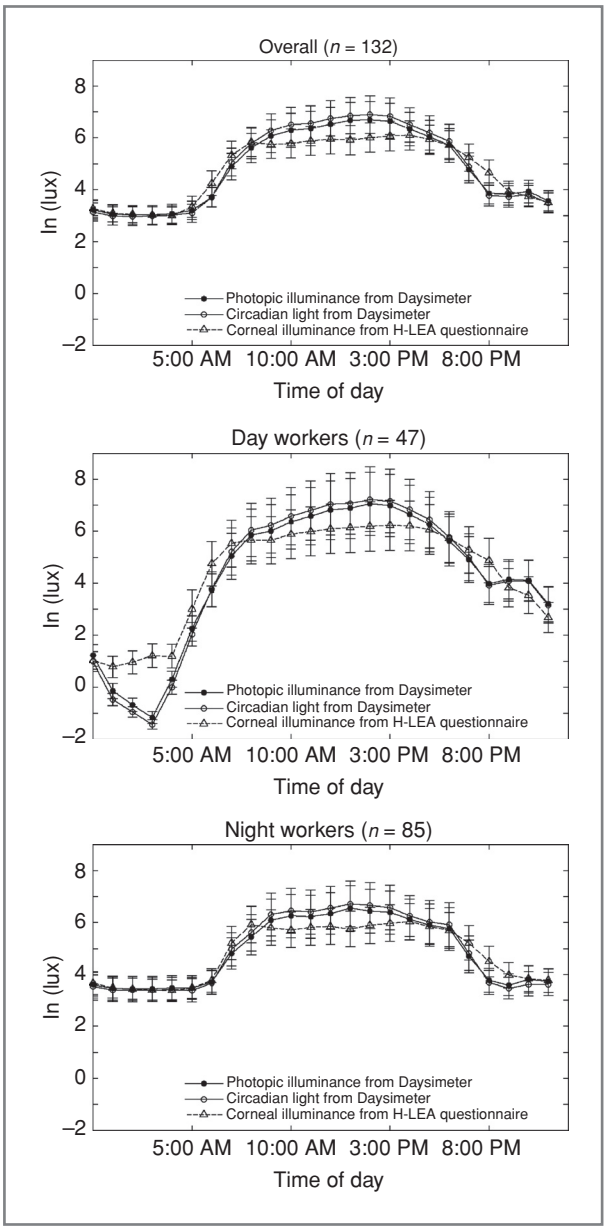

Figure 3. Mean hourly light values over 24-hour period (averaged over 7 days) as measured by the Daysimeter and the H-LEA questionnaire (means and SDs as indicated in graph by error bars), overall and stratified by night work status in validation subgroup of 132 participants from the NHS2.

Discussion

We aimed to validate a paper questionnaire in relation to standard light measures of both sunlight and artificial light sources, and we found strong correlations of 0.68 and above for light measures calculated from our paper-based H-LEA questionnaire compared to both standard photopic illuminance as well as short-wavelength "circadian" light, both in women who worked day shifts and night shifts.

In validating a paper-based light questionnaire against light measures obtained from a standard light meter, it is important to use light meters that measure light as accurately as possible. The Daysimeter in our study had to be worn close to the eye to estimate light falling on the cornea.

There is scant literature on the validity of using paper-based light exposure questionnaires to estimate actual light exposure. Most prior studies looked only at sun exposure as measured by UVR dosimeters. O'Riordan and colleagues (15) compared UVR exposure of mothers and infants less than 1 year old measured by the dosimeter worn on the wrist with a measure of estimated exposure using a diary based on recall by mothers of the

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Table 3. Kendall tau and Spearman correlation coefficient (95% CI) for correlation between corneal illuminance approximated from H-LEA questionnaire and photopic illuminance and circadian irradiance from Daysimeter measurements (criterion standard)[a]

	Kendall τ	Crude Spearman correlation r^a	Adjusted Spearman correlation r^a
Photopic illuminance			
Overall ($n = 132$)	0.57	0.72	0.72
Day workers ($n = 47$)	0.63	0.77	0.77
Night workers ($n = 85$)	0.54	0.68	0.68
Day 1	0.57	0.71	0.71
Day 2	0.61	0.76	0.76
Day 3	0.59	0.74	0.74
Day 4	0.55	0.69	0.70
Day 5	0.55	0.69	0.69
Day 6	0.54	0.68	0.69
Day 7	0.59	0.73	0.73
Circadian light			
Overall ($n = 132$)	0.58	0.72	0.73
Day workers ($n = 47$)	0.63	0.78	0.78
Night workers ($n = 85$)	0.55	0.69	0.69
Day 1	0.57	0.72	0.72
Day 2	0.61	0.76	0.77
Day 3	0.59	0.74	0.74
Day 4	0.56	0.70	0.70
Day 5	0.55	0.70	0.70
Day 6	0.55	0.69	0.69
Day 7	0.59	0.74	0.74

[a]All correlation and Kendall τ coefficients are statistically significant ($P < 0.0001$). Crude values are adjusted for nurses' ID only; adjusted values are adjusted for nurses' ID, age, BMI, day of the 7-day collection, and whether or not they were current night workers.

prior 4 days. Study authors concluded that the association between estimated exposure and dosimeter readings was poor and needed improvement, citing the possible bias resulting from recall error. Thieden and colleagues (16) asked 44 Danish adult indoor workers to record outdoor activity between 7:00 AM and 7:00 PM in 30-minute intervals for a mean of 13 days during holiday periods and a mean of 17 days during work periods (June–September). Participants were asked to record their time outdoors, the location, and clothing. Authors calculated skin area exposure hours from the diaries and found a highly significant ($P < 0.001$) correlation between the calculated exposure hours with UVR exposure as measured by dosimeter worn on the wrist. They concluded that questions other than exposure hours (e.g., type of clothing) were not crucial to obtain valid information about UV exposure, and by reducing the number of questions in the diary, participant compliance would likely increase. In 2006, Thieden and colleagues (19) used a shortened version of the diary and achieved better compliance among 407 participants, including children, adolescents, and adults, who were asked to answer "yes" or "no" to questions about sun exposure behavior on a daily basis for a total of 54,943 participation days. Diary completion rate was 95%, and subject compliance rate for wearing the dosimeter on days the diary was completed was 86.4%. Thieden and colleagues found a tendency to wear the dosimeter less during weekends than on workdays. Chodick and colleagues (14) similarly asked 124 volunteers from a cohort of radiologic technologists to wear a dosimeter on the shoulder and complete a daily activity diary for 7 days, listing all activities undertaken for each 30-minute interval between 9:00 AM and 5:00 PM. Results showed a significant correlation between the amount of recorded time spent outdoors and personal UVR dose measurement. In a pilot study, O'Riordan and colleagues (18) asked 27 participants to wear a personal dosimeter and complete a sun habits diary for 4 consecutive days, including recording their primary activity for each hour between 10:00 AM and 4:00 PM. Results indicated a fair agreement between personal UVR exposure as measured by the dosimeter and time spent outside as reported in the diaries ($r_s = 0.32$, $P = 0.03$).

A paper-based log of light exposure is superior to other methods of assessing light exposure in larger scale cohort studies because it is easy to administer. Strengths of the H-LEA questionnaire developed for this study include that it asks participants in the form of a structured diary

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to record light exposure on an hourly basis, limiting the potential for measurement error. The H-LEA questionnaire could possibly be further simplified by including only 3 major light categories-–indoors, outdoors, and darkness. Other strengths of our study are high rates of participation and success with participants enrolled from a well-documented cohort with longitudinal information on a number of important covariates such as BMI, age, and shift work status.

Limitations of our study include the potential for noncompliance with wearing the Daysimeter (i.e., our criterion standard). A likely reason for noncompliance is that the Daysimeter is a conspicuous object worn on the head, and participants may have found this uncomfortable or felt awkward wearing it in public places. Note, however, that this is not a limitation for the paper questionnaire. Compliance would likely be much higher if study participants were asked only to fill out the paper questionnaire, as opposed to also wearing a light meter for 7 days. Furthermore, participants in our study were asked to complete several other questionnaires, including keeping a diary of daily activity; participants are likely to be more compliant with less paperwork. Another limitation of our findings is that they may not be reflective of self-reported past light exposure. Future studies should assess the validity of the H-LEA questionnaire when used to assess average light exposure during a past period of time, as opposed to current light exposure akin to a structured diary, like in our study. Our estimate for the amount of light derived from sun exposure was conservatively based on 2,000 lux and may have underestimated actual light levels. However, correlation coefficients are based on the relative ranking of light levels; hence, our results should not have been impacted by this. Whether the validity of our questionnaire, which is based on a group of middle-aged, highly motivated and health care educated Caucasian women can be generalized to other population groups including men or other age and ethnic groups needs to be studied. Similarly, women who volunteered to participate in our study appeared more health conscious, as reflected in the fact that night workers in the validation group had much lower rates of smoking than night workers in the overall NHS2 cohort (see Table 2) and were thus perhaps more compliant.

In summary, our study provides evidence that adults are able to report exposure to both artificial and natural light using the H-LEA questionnaire with shown validity. This tool could prove useful in large-scale studies examining associations between light exposure and various disease endpoints.

Disclosure of Potential Conflicts of Interest

The content of this article is solely the responsibility of the authors and does not necessarily represent the official views of the Department of Health and Human Services/CDC/NIOSH/NIH. Funding agencies did not have any role in the design of the study; the collection, analysis, or interpretation of the data; the decision to submit the manuscript for publication; or the writing of the manuscript. S.W. Lockley, consultant, Wyle Integrated Science and Engineering; consultant, Naturebright, Sound Oasis, Thomas Jefferson University; research grants, Philips Lighting, Alcon, and Philips-Respironics; unrestricted equipment gifts, Philips Lighting and Bionetics Corp.; unlicensed patent for use of short-wavelength lilght for circadian resetting; unrestricted gifts, Swinburne University and Optalert, Pty, Australia; expert testimony related to shift-work; multiple travel and accommodation support and honoraria for speaking at conferences/meetings. No other potential conflicts of interest were disclosed.

Authors' Contributions

A. Bajaj collected, analyzed, and interpreted data and prepared the manuscript; B. Rosner analyzed data and prepared the manuscript; S. Lovkley collected data and prepared the manuscript; and E.S. Schernhammer provided funding, collected, analyzed, and interpreted data, and prepared the manuscript.

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