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Vali, K., et al.

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CIE Central Bureau
Babenbergerstrasse 9/9A
A-1010 Vienna, Austria
Tel.: +43 1 714 31 87
e-mail: ciecb@cie.co.at — www.cie.co.at

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LIGHT EXPOSURE OF OLDER ADULTS LIVING ALONE: A PILOT STUDY

Vali, K.[1], Au-Yeung, W-T. M.[2], Kaye, J.[2], **Pierson, C.**[1]

[1]Oregon State University, Corvallis (OR), USA, [2]Oregon Health & Science University, Portland (OR), USA

Email: clotilde.pierson@oregonstate.edu

Abstract

Ocular light exposure is essential for regulating circadian rhythms, influencing sleep-wake cycles and several physiological and psychological processes. Inappropriate light exposure can impair sleep, mood, cognition, and overall well-being, posing particular risks for older adults experiencing age-related sleep disturbances and cognitive decline. However, objective data on the light exposure of older adults remain limited. In this observational study, we monitored the winter and summer light exposure of 16 older adults living alone using wearable spectral sensors. We derived the Circadian Stimulus and Melanopic Equivalent Daylight Illuminance (mEDI) for each data point and analyzed their light exposure during the daytime, evening, and nighttime. Our results indicate that older adults tend to have relatively low daytime exposure, with a median daytime mEDI of 31,2 lux, but did not experience light pollution at night. Furthermore, an analysis of building characteristics revealed only a modest association between light exposure and the window-to-wall ratio.

Keywords: Light, Older Adults, Circadian Rhythms, Non-visual Effects, Wearable Sensors

1 Introduction

Intrinsically photosensitive retinal ganglion cells (ipRGCs), discovered in the early 2000s, are distinct from rod and cone photoreceptors because of their role in mediating non-visual effects of light. These cells project to brain regions such as the suprachiasmatic nucleus (SCN) for circadian synchronization, or the preoptic area for sleep regulation and mood modulation (Lazzerini Ospri et al., 2017; Rupp et al., 2019). Inappropriate light exposure—whether in terms of timing, intensity, or spectral content—can lead to adverse health outcomes over the long term, such as increased risks of chronic diseases (Hunter and Figueiro, 2017). In the short term, misaligned or insufficient light exposure has been linked to disruptions in sleep, alterations in mood, and impairments in cognitive function (Blume et al., 2019; Boyce, 2022). Consequently, optimizing non-visual responses to light in humans has become increasingly important. IpRGCs do not conform to the traditional photometric system due to their spectral sensitivity to short-wavelength light (~480 nm) via the photopigment melanopsin (Lucas et al., 2014). Exposure to bright, blue-enriched light during the day has been recommended to enhance alertness and synchronization of circadian rhythms, while dim, warmer-toned light in the evening is favored to promote sleep (Blume et al., 2019; Boyce, 2022). However, individuals in developed countries often spend most of their time indoors nowadays (Klepeis et al., 2001), resulting in a frequent misalignment with the sun's light–dark cycle. This modern lifestyle issue is particularly significant for populations at risk of sleep disruption, mental health challenges, or cognitive decline.

Older adults represent one such vulnerable group who experience more sleep disturbances than younger adults, including insomnia, fragmented sleep, and advanced sleep phase syndrome (Neikrug and Ancoli-Israel, 2009). For instance, research indicates that up to 50% of older individuals experience challenges such as difficulty maintaining sleep, early morning awakenings, or insomnia (Foley et al., 1995). The average nighttime sleep duration for older adults is 6–6,5 hours, which falls short of the recommended 7–8 hours for optimal health (Ohayon et al., 2004). Moreover, in the United States, the overall prevalence of sleep disorders within this population is estimated to range from 21% to 34% (Gulia and Kumar, 2018). These sleep challenges might be linked to age-related physiological changes, such as a weaker melatonin secretion (Wurtman, 2000) and yellowing and thickening of the lens, which diminishes the transmission of short-wavelength blue light to the retina (Blume et al., 2019; Gulia and Kumar, 2018). In addition, older adults are at a heightened risk of cognitive decline (Harada et al., 2013; Salthouse, 2009). Light exposure seems to be one contributing factor to this risk, with studies showing an association between lower levels of outdoor light exposure and increased odds of cognitive impairment (Kent et al., 2014; Voigt et al., 2024). Given the essential role of light in regulating sleep-wake cycles and supporting cognitive processes, ensuring healthy light exposure made of bright days and dark nights is especially critical for older adults. Evaluating the light exposure of older adults is therefore a crucial first step in promoting circadian health, cognitive resilience, and overall well-being in this population.

Previous studies have examined older adults' light exposure in institutional environments, such as nursing homes and dementia units (Ancoli-Israel et al., 1997; Figueiro et al., 2012; Kolberg et al., 2021; Riemersma-van der Lek et al., 2008; Shochat et al., 2000). These studies found that older adults living in such settings are typically exposed to low levels of light during the daytime, often insufficient to properly stimulate circadian rhythms or promote healthy sleep-wake patterns. While these studies provide valuable insights, it is important to highlight that most of them measured light exposure at the wrist and reported it in photopic lux—two methodological limitations that may not accurately capture the circadian-effective light exposure received by participants. Additionally, the findings from these studies are primarily drawn from institutional settings, which may not reflect the experiences of older adults living independently. For instance, older adults living alone represent approximately 27% of this population in the United States (US Census Bureau, 2023), yet this group remains significantly underrepresented in lighting research. It remains uncertain how light exposure patterns in institutional settings compare to those in private homes, where daily routines, access to daylighting, and lighting conditions can vary widely (Olsen et al., 2016). Given these gaps, there is a clear need for field studies that accurately assess the daily light exposure of older adults living independently at home using non-visual light metrics.

In this observational study, we aimed to address this gap by evaluating the light exposure of older adults living independently at home. Leveraging recent advances in wearable spectral sensor technology, we continuously monitored the light exposure of 16 older adult participants over two weeks in both winter and summer. These measurements were analyzed to better understand the quantity and quality of light to which older adults living alone are exposed, as well as the daylighting characteristics of their home environments that influence this light exposure.

2 Methods

2.1 Study Design

16 healthy older adults (aged 65 years or older) from the Portland, Oregon metropolitan area participated in the study and provided written informed consent (IRB# HE-2023-437). Data collection occurred over two distinct two-week periods for each participant: one during the winter months (January to March 2024) and one during the summer months (July and August 2024). These two data collection periods were designed to capture seasonal variations in light exposure. Participants wore a wearable spectral sensor as a necklace on their chest throughout both periods, which measured spectral irradiance every minute to assess their light exposure. Apart from wearing the device, they were not required to perform any specific tasks and continued their daily routines.

At the beginning of each data collection period, we conducted home visits to collect information about the daylighting characteristics of the home, including the window-to-wall ratio (WWR), window blind at the time of the visit, and window orientation in each room occupied by the participants. During these visits, we also provided detailed instructions for sensor placement and advised participants to wear the sensor or position it next to a flat surface when sleeping or showering to ensure that it faced forward and remained uncovered.

2.2 Participants

We recruited 16 participants from the Digital Technology Core cohort of the Oregon Alzheimer's Disease Research Center at Oregon Health & Science University (OHSU). The group is composed of individuals aged 62 and older who live in the Portland, Oregon metropolitan area, with homes equipped with digital sensors to track daily activities such as walking, sleeping, and medication adherence. Additionally, these participants take part in annual cognitive assessments and complete weekly health questionnaires, providing an ongoing data stream that helps researchers understand aging in a home setting and their cognitive health trends (Beattie et al., 2020; Kaye et al., 2011). This established monitoring system made the cohort an excellent choice for our research, as it allowed us to integrate detailed home occupancy data into our analysis. To be eligible for this study, participants had to reside in single-person households—pets were allowed—so that occupancy data could be attributed to a single individual. Additionally, eligibility criteria required that participants maintain their typical daily routine (for example, no planned travel) over the 2 2-week data collection periods, have stable medication usage during these periods, and possess the cognitive ability to independently follow the study protocol.

Our study sample ranged in age from 73 to 101 years (mean = 84 years) and included 4 males and 12 females. All participants self-identified as non-Hispanic/Latino and reported White as their race, and each indicated English as their primary language. Participants' education levels ranged from 12 to 21 years and their clinical and neuropsychological assessments were consistent with cognitive functioning that is considered normal for age. Although all 16 participants took part in the winter data collection phase, one individual withdrew prior to the summer phase.

2.3 Equipment

We employed the Speck sensor (Blue Iris Labs, 2024), a compact device capable of measuring spectral light data, for the light exposure measurements. The participants wore the sensor, which has a 5 cm diameter and weighs 25 grams, as a necklace on their chest. To enable near real-time transfer of light data to cloud storage, the sensor connects via Bluetooth to a Raspberry Pi unit (Raspberry Pi Foundation, 2019). In our setup, each participant's home housed a Raspberry Pi gateway, which allowed us to monitor incoming data continuously and reach out to the participant if the sensor was not in use or if data collection was disrupted.

The sensor is pre-calibrated and offers sufficient battery life and on-board memory to enable data collection for at least two weeks when out of the gateway's range. It reports spectral irradiance values across the 400 to 700 nm range in 5 nm increments, along with several additional light metrics such as photopic illuminance (E_v), Correlated Color Temperature (CCT), Circadian Stimulus (CS), and melanopic Equivalent Daylight Illuminance (mEDI). While the Speck sensor is calibrated for typical daytime light conditions, its specifications indicate limitations in measuring E_v below 10 lux.

Passive infrared (PIR) motion sensors installed in participants' homes by the Oregon Center for Aging & Technology at OHSU (ORCATECH) were used to track participants' movement throughout the home. These sensors detected motion and logged timestamps which allowed us to determine which rooms participants were in and when (Muurling et al., 2023). Door sensors also captured when participants entered or left their residence.

2.4 Data Processing and Analysis

The dataset for this study initially comprised 628 109 data points collected by the wearable sensors, from which we used the mEDI and CS values provided by the sensor. The mEDI quantifies the effectiveness of light in stimulating the melanopsin-containing ipRGCs (CIE, 2018), while CS is a metric that estimates the potential of light exposure to suppress melatonin and shift circadian rhythms (Rea and Figueiro, 2018).

To account for periods when participants were not wearing the sensor, we applied a compliance filtering step via a visual analysis of the variability of participants' light exposure. Data points showing no daytime fluctuation indicative of some movement were removed, as these are typical of periods when the sensor is not worn. After filtering, 550 731 data points remained, with a mean (± SD) of 34 421 (± 8 103) per participant.

After filtering, we first analyzed the participants' light exposure through descriptive statistics and evaluated whether participants' light exposure met recommended thresholds for optimal non-visual responses to light. The thresholds and their associated exposure periods were defined based on guidelines for mEDI and CS from Brown et al. (2022) and Underwriters Laboratories (2019) respectively. Specifically, light exposure recommendations were interpreted as follows for mEDI: above 250 lux from 6:00 AM to 7:00 PM, below 10 lux from 7:00 PM to 10:00 PM, and below 1 lux from 10:00 PM to 6:00 AM. For CS, the guidelines recommend a minimum of two continuous hours of light exposure with a CS value of 0,3 or higher during daytime (7:00 AM to 4:00 PM), a CS value of 0,2 or lower in the evening (5:00 PM to 7:00 PM) and of 0,1 or lower at night (8:00 PM to 7:00 AM). These thresholds and associated time windows were used to compute compliance percentages: for mEDI and for CS during the evening and night, we calculated the percentage of time meeting the thresholds; for CS during the daytime, we quantified the percentage based on the longest continuous period meeting the criterion, relative to a 2-hour target.

To further explore individual variability in light exposure, we also assessed the interdaily stability (IS) of each participant's light exposure. IS quantifies how consistently light exposure patterns repeat across days, with values ranging from 0 (random day-to-day variation) to 1 (perfectly stable exposure). Higher IS suggests strong coupling to environmental time cues, while lower IS indicates irregular exposure, which has been associated with circadian rhythm disruptions in older adults (Van Someren et al., 1999).

Additionally, we examined the relationship between the measured light exposure and the window orientation, WWR, and window blind position at the time of visit (closed, intermediate, opened) in each room. It is important to note that the window blind position reflects the state of the blinds only at the time of the visit and not throughout the entire measurement period; however, this variable remains of interest because occupants tend to adjust their blinds infrequently (Bennet et al., 2014). For these analyses, the Speck sensor data were used from the room the participant was in, as determined by home occupancy data provided by ORCATECH. All analyses were conducted using R software (R Core Team, 2024).

3 Results and Discussion

3.1 Older Adults' Light Exposure

Figures 1 and 2 show the distribution of mEDI and CS values for all participants over the entire study period. A detailed analysis of the light exposure of older adults revealed that daytime light exposure is relatively low and consistent between the two seasons, with a median daytime mEDI of 31,2 lux and a median CS of 0,06 which indicates an overall dim light environment during the day. Evening light exposure was even lower, with a median evening mEDI of 11,4 lux and a median CS of 0,03. The median was chosen rather than the mean since some participants were occasionally exposed to unusually high light levels, particularly for mEDI, which could skew the average and misrepresent their light exposure. In summer, older adults were exposed to morning light earlier (around 5:30 AM) than in winter (around 7:00 AM), although their light exposure extended similarly throughout the evening and early night in both seasons.

Our findings corroborate existing literature (Kolberg et al., 2021; Shochat et al., 2000), which consistently indicates that older adults tend to receive inappropriate light exposure during the daytime. Specifically, older adults living independently at home do not achieve sufficient daytime light exposure, which could adversely affect their mood and daytime alertness, as well as disrupt their sleep patterns at night. Such a pattern of light exposure extends twilight and weakens the distinction between day and night for the circadian system, creating a risk for suboptimal circadian and physiological responses (Chellappa et al., 2011; Obayashi et al., 2014).

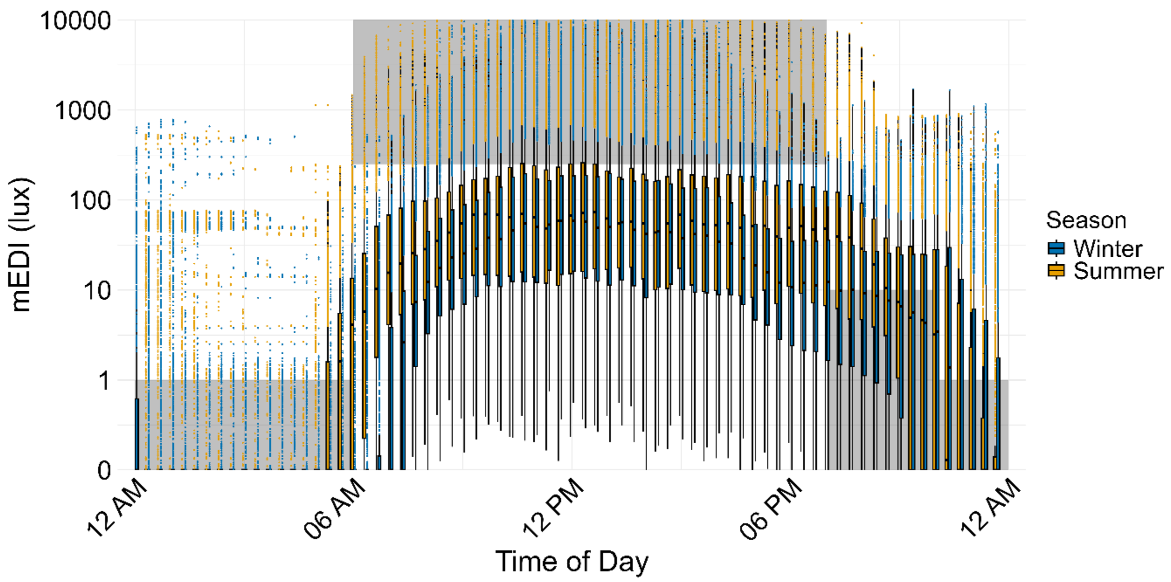

Figure 1 – Distribution of mEDI values for all participants across the entire study period, aggregated into 30-minute bins and separated by winter and summer conditions. The grey-shaded areas represent the recommended thresholds by Brown et al. (2022).

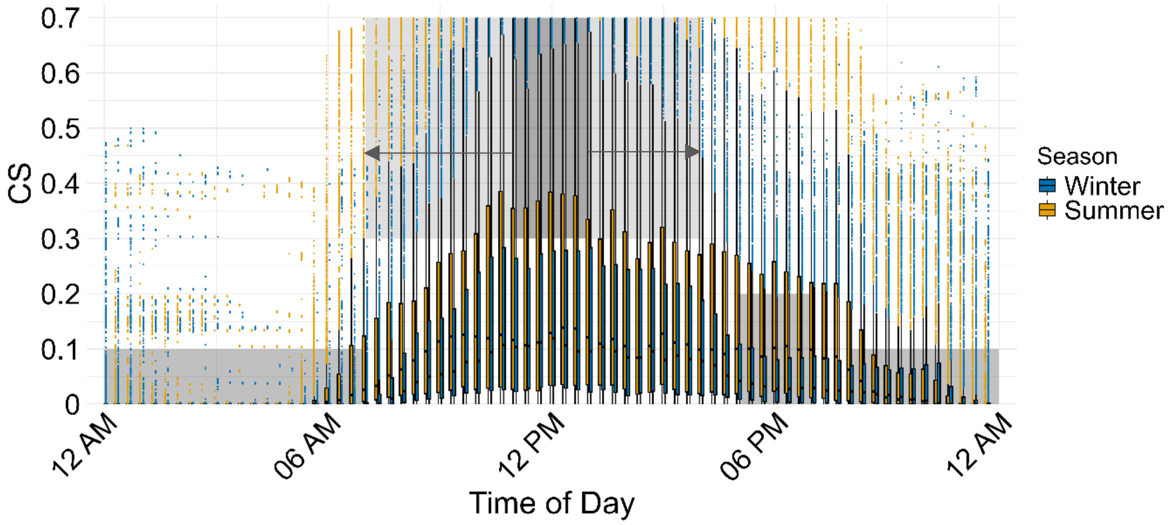

Figure 2 – Distribution of CS values for all participants across the entire study period, aggregated into 30-minute bins and separated by winter and summer conditions. The grey areas represent the recommended thresholds based on UL (2019). The darker grey area during daytime indicates a continuous 2-hour period during which the threshold should be met, and the adjacent arrows illustrate that this window can shift within the broader daytime period.

At night, especially between 12:30 AM and 5:30 AM, the light levels to which the participants were exposed dropped to nearly 0 lux in mEDI and 0 in CS. These results indicate that, in this study, older adults' nighttime light exposure was minimal, suggesting that light pollution (disruption of natural light levels due to electric light sources, leading to harmful environmental consequences for humans, wildlife, and climate) was not a significant concern in their sleep environment. This contrasts with findings from previous studies that infer older adults' sleep environments are affected by elevated outdoor light pollution in urban areas—measured using satellite-based methods—and show an association between outdoor light pollution and mental health disorders (Jin et al., 2023), dementia (Mazzoleni et al., 2023), or Alzheimer's disease (Voigt et al., 2024) in older adults. Satellite-based methods assess outdoor light pollution across large areas, which may not accurately represent indoor bedroom conditions experienced by individuals (Huss et al., 2019). In contrast, the wearable sensors used in this study offer a more direct and precise measure of the actual bedroom light environment. However, given the pilot nature of this study and its small sample size, these findings might not fully represent the indoor bedroom light conditions of the broader older adult population living in urban areas. Further research with larger and more diverse cohorts is needed to explore this relationship in greater depth.

When compared against existing recommendations for optimal non-visual responses to light, the participants' light exposure did not meet the recommended values for most of the daytime, especially in winter. In contrast, nighttime light exposure generally met the recommended values. The mean percentages of time during which the derived mEDI values met the set thresholds were **13,7%** during the daytime period, **48,2%** during the evening period, and **80,9%** during the nighttime period. Similarly, for CS, the mean percentages of time meeting the thresholds were **24,5%** of daytime, **49,5%** of evening, and **78,4%** of nighttime.

Based on Figure 3, IS values were slightly higher during both the winter and summer seasons compared to the entire data collection period. This finding indicates that participants exhibit more consistent light exposure patterns within individual seasons than throughout the year. However, it is important to note that the overall IS values observed in our study were relatively lower than those reported in other research. For example, Liao et al. (2025) reported an average IS of 0,56 in a large sample of U.S. adults.

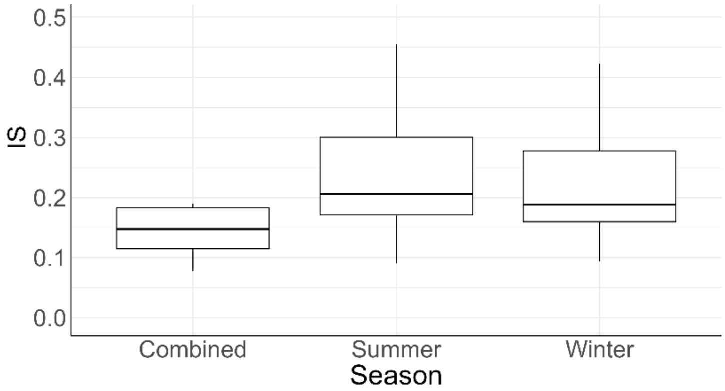

Figure 3 – Distribution of IS values for light exposure across participants during summer, winter, and the combined monitoring period.

3.2 Daylighting Home Characteristics Affecting Light Exposure

We examined the association between participants' light exposure and the daylighting characteristics documented during our initial home visits. Figures 4–6 show the relationship between light exposure and three daylighting home characteristics, the WWR, the window blind position at time of visit, and the window orientation.

As shown in Figure 5, our results indicate only a very modest relationship between the WWR in a room and the mEDI and CS levels to which a participant is exposed in this room. While a stronger association might have been expected, several confounding factors—such as glazing characteristics, the participant's position relative to the window, the use of blinds, and electric lighting—may influence this relationship and are not accounted for in this figure. Previous simulation-based studies have suggested that increasing WWR leads to better light exposure for non-visual responses (Potočnik and Košir, 2021). However, our results show that, in real-world settings, the effect of WWR on light exposure may be quite limited due to the interplay of these additional factors.

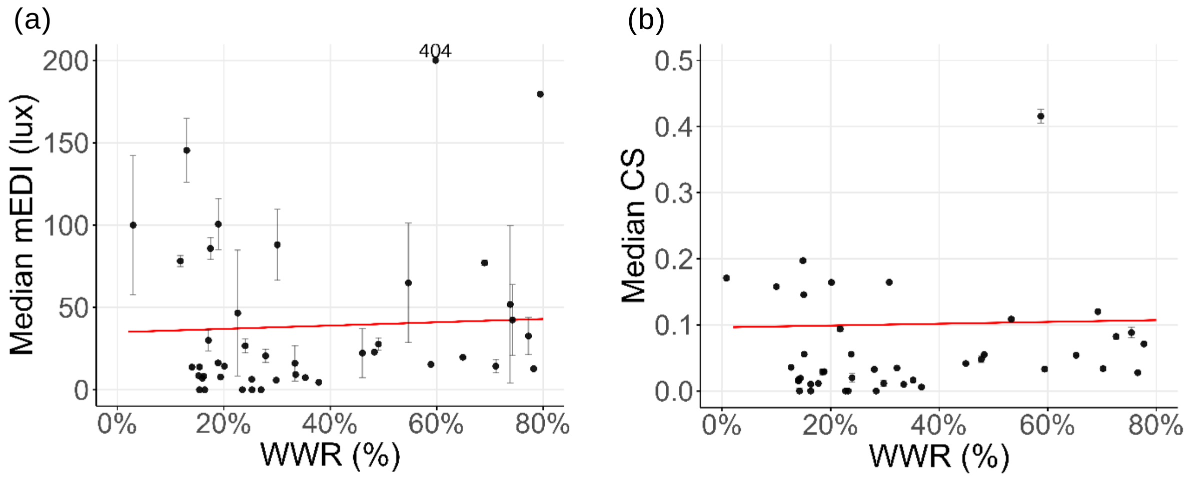

Figure 4 – (a) Relationship between WWR and median mEDI, and (b) relationship between WWR and median CS for the rooms for all participants. Each black point in both plots represent the median value for a single room across the data collection period, with vertical bars showing ±1 standard error. The red line represents the linear regression fit.

As shown in Figure 5, the participants' light exposure in a room does not appear to be influenced by the blind position in that room, as there is no clear relationship between blind position and the mEDI or CS levels to which participants were exposed. This finding does not align with those of Karmann et al. (2023), whose study on office buildings showed higher melanopic exposure when blinds were consistently open or automated. However, our results should be interpreted cautiously, as the blind position recorded here reflects only the state of the blinds at the time

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of the researcher's visit, rather than throughout the entire study period, while the light exposure data represent the full study duration.

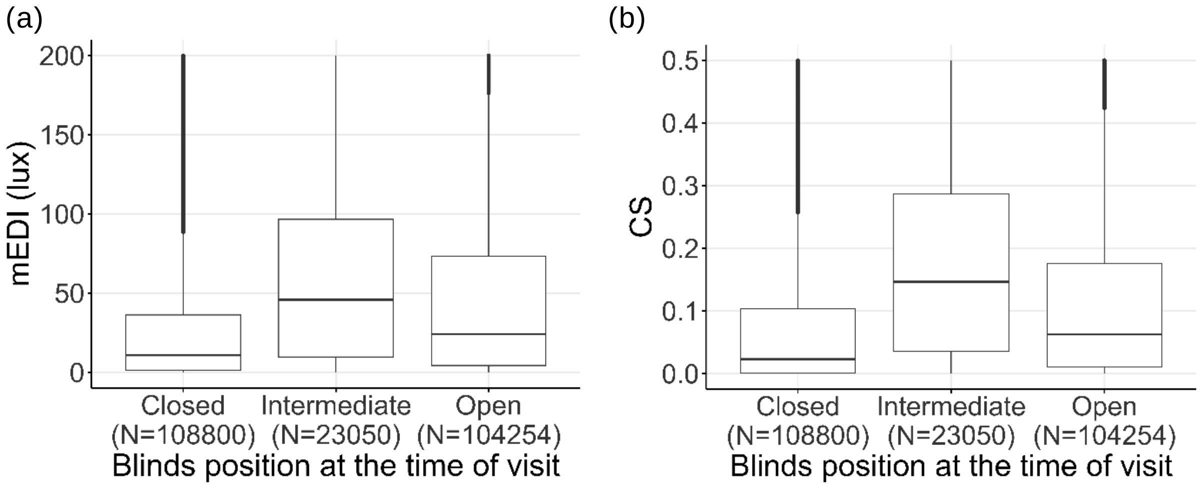

Figure 5 – (a) mEDI values by blind positions, and (b) CS values by blind positions for rooms in both Summer and Winter. Each box in both plots represent the spread of all room-level values across the data collection period.

Figure 6 shows that, aside from the Northeast window orientation, differences in the light exposure of participants—expressed in terms of mEDI—across room window orientations are subtle, suggesting that window orientation may not strongly influence participants' light exposure. Caution is needed when interpreting these results, as the number of data points in the boxplots varies across orientations. These findings put in perspective those from simulation-based studies (Campano et al., 2024; Potočnik and Košir, 2021), which report higher mEDI for south and east window orientations and consistently lower values for north window orientations. Once again, the discrepancy may stem from confounding factors—such as individual behavior and other environmental conditions—that limit the effect of window orientation on light exposure in real-world settings.

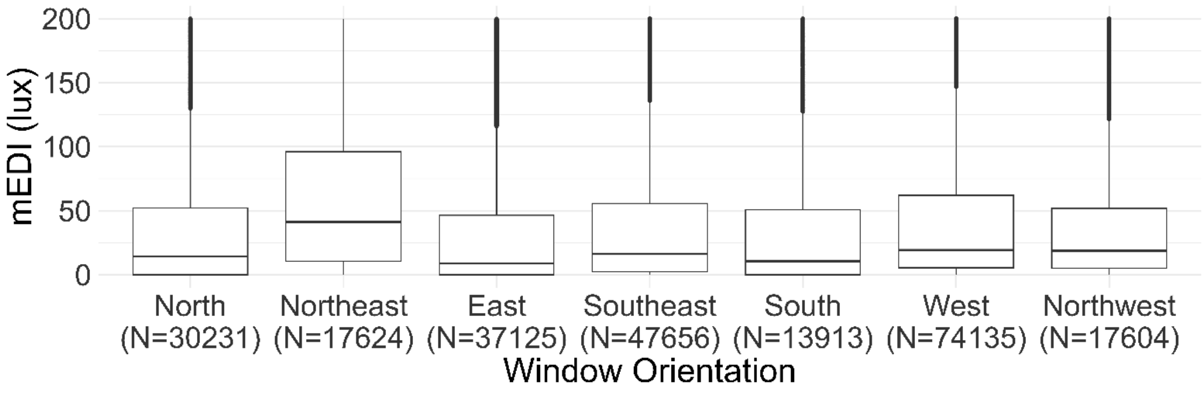

Figure 6 – Distribution of mEDI values by window orientation during daylight hours. Each box represents the spread of all room-level values across the data collection period. Results for CS values showed a similar pattern and are therefore not displayed.

3.3 Limitations

There are some limitations to this study that should be considered. Since our analysis relied exclusively on wearable light sensors, the measured light data may not accurately reflect the light reaching the participants' eyes. The wearable sensors are worn lower than the eye-level on the chest, and do not account for head and eye movements. In addition, the wearable sensors could have been obstructed by clothing, shaded by body parts, or flipped, which would typically lead to an underestimation of the participant's light exposure.

It should also be noted that our dataset included 42,3% of E_v measurements below 10 lux. While many of these values occurred during the night, some were also during the day. Given the sensor's measurement bias in light conditions below 10 photopic lux, consistently measuring 1–2 lux lower than what a research-grade spectrometer would measure according to our tests, these low-light condition results should be interpreted with caution.

Finally, the study had a relatively small sample size due to its pilot nature and a high proportion of female and White participants, both of which limit the generalizability of these findings.

4 Conclusion

In this study, we evaluated the light exposure of older adults living independently at home using wearable spectral sensors. Our goal was to assess whether older adults' light exposure supports their non-visual responses to light, including their sleep and cognition, and what daylighting characteristics of their home environment influenced their light exposure indoors.

Our findings suggest that participants generally received insufficient daytime light exposure, with a median daytime melanopic equivalent daylight illuminance (mEDI) of 31,2 lux, and only about 13,7% of daytime periods meeting the recommended thresholds, indicating very low daytime light exposure. Evening light exposure was relatively better, meeting the recommendations for 48,2% of the evening, with a median mEDI value of 11,4 lux. Nighttime light exposure remained minimal, suggesting that nighttime light pollution is not a problem for the participants.

Overall, the data show a pattern characterized by sufficiently dark nights but persistently low daytime illuminance, fails to provide a strong day–night contrast, which may impair circadian entrainment and lead to sleep disruption, as well as suboptimal daytime cognitive performance and mood. Our data do not reveal significant effects of orientation or blinds usage on light exposure. Only a modest relationship with WWR was observed, suggesting that while window size may play a partial role, other characteristics of the home environment, such as glazing characteristics and electric lighting, may also influence the participants' light exposure.

Future work should aim to replicate and expand this study with a larger and more diverse sample, including older adults from various demographics, living arrangements, and geographical regions, while also assessing their light exposure over the long term. Considering the established links between light exposure, sleep regulation, and cognitive function in older adults, such efforts are critical to developing effective interventions that promote well-being and healthy aging in this population.

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