The bright side of life – Daytime light exposure and well-being in younger and older adults' daily lives

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Abstract

Objective: People today spend most of their time indoors which likely results in suboptimal lighting conditions and may negatively impact their health and well-being. However, research on the effects of light exposure in daily life is sparse. In the present work, we address this gap by examining the links between daily light exposure with different well-being indicators.

Methods: In the present study, 30 younger (M_{age}=24.1, *SD*=3.2, 47% women) and 29 older adults (M_{age}=67.4, *SD*=5.16, 59% women) wore a light sensor as a pendant for 10 consecutive days in their daily lives, sampling light exposure every 10 seconds. They reported their momentary positive affect (PA), negative affect (NA), vitality, and alertness up to six times per day. We analyzed associations of light exposure in the previous 5, 60, and 180 minutes with these different aspects of well-being.

Results: Multilevel models showed that both brighter overall levels of melanopic equivalent daylight illuminance (mEDI) and longer time spent above 250 lx mEDI were associated with higher high arousal PA, vitality, and alertness but not with lower NA. Additional analyses indicated that for PA and vitality this association may mainly exist for natural daylight whereas the light source did not matter for alertness. Exploratory analyses of higher thresholds (500-750 lx mEDI) partly yielded stronger effects.

Conclusion: This pattern of results may suggest energizing and activating effects of light exposure and future research should determine whether light exposure behavior could be a target for interventions to increase health and well-being in daily life.

Key words: light exposure, ambulatory assessment, well-being, melanopic lx, daylight

Introduction

People spend a lot of their time indoors (Schweizer et al., 2007) which likely results in suboptimal lighting conditions and may negatively impact their health and well-being. However, research on the effects of light exposure in daily life is sparse and do not allow reliable conclusions regarding associations of light exposure with different aspects of well-being (see Böhmer et al., 2021, for a review). Current recommendations suggest that people should experience relatively bright light during the day, low light in the evening, and very little to no light at night for optimal functioning (Brown et al., 2022). Although some recent studies support this general idea (Didikoglu et al., 2023; Peeters et al., 2022), these recommendations for optimal light exposure have not yet been systematically tested in daily life. Thus, light exposure in daily life is currently an understudied health behavior in the context of well-being. In the present work, we address this gap by examining the links between light exposure in daily life with different well-being indicators. In the present study, 30 younger and 29 older adults wore a light sensor as a pendant for 10 consecutive days in their daily lives and they reported on their momentary positive affect (PA), negative affect (NA), vitality, and alertness up to six times per day through a smartphone app. Combining passively collected data on light exposure and self-report measures of mental health in an ambulatory assessment design provides the means to approach the short-term effects of meeting light exposure recommendations on health relevant outcomes in individuals' everyday lives.

Light exposure in daily life

Humans perceive light through different photoreceptors in their retina. While vision is mediated through rods and cones, non-visual effects of light are mainly mediated by intrinsically photosensitive ganglion cells (ipRGCs; Hattar et al., 2002). ipRGCs are light-receptive cells in the retina that play a critical role in regulating the circadian system, with influence on the sleep-wake cycle, and other physiological processes, such as hormone expression (Palumaa et al., 2018). Projections from the ipRGCs to non-visual brain regions may mediate the effects of light on alertness, emotional processes, and cognitive functioning (Blume et al., 2019; Chellappa et al., 2011). The ipRGCs are maximally sensitive to the blue colour spectrum of light (approximately 480 nm; Bailes &

Lucas, 2013). As a result, the standard photometric quantities used to describe brightness and luminous sensation (e.g., photopic lux) do not accurately represent the spectral sensitivity of ipRGC-dependent responses to light; melanopic EDI (mEDI; weigthed according to the spectral sensitivity of ipRGCs, i.e., more towards the blue spectrum) has been developed as the new metric to quantify light exposures that target nonvisual responses (Brown, 2020).

Historically, day and night have led to predictable patterns in light and darkness throughout a 24-hour day and physiological and psychological processes were synchronized to these patterns. However, with today's largely indoor lifestyle and electric lighting, people's daily light exposure is more and more decoupled from this natural rhythm. Recent recommendations suggest that for optimal health and functioning people should experience light levels > 250 lx mEDI during the day, < 10 lx mEDI in the three hours before sleep, and < 1 lx mEDI during sleep (Brown et al., 2022). The recommended optimal levels of lighting during the day are often not reached, as indoor electrical lighting is magnitudes darker than outdoor daylight (e.g., indoor office lighting: ~300–500 photopic lx vs. outdoor daylight (overcast): ~10,000 lx vs. outdoor daylight (sunny): >50,000 lx) with office lighting generally designed to reach certain levels of photopic lux, not mEDI (e.g., for indoor office lighting a respective conversion to 170-400 lx mEDI is justified, depending on whether fluorescent or LED light sources are installed; for outdoor daylight, photopic and mEDI lx are almost equal in most scenarios). At the same time, the typical indoor electrical lighting is substantially brighter than the light levels recommended for evening light exposure after sunset. Overall, these behaviors may result in people experiencing too little light during the day and too much light in the evening with potential negative health consequences.

Light exposure and well-being

Especially little light during the day may have detrimental effects on people's well-being, as research has established a general association between light and psychological well-being (e.g., Landvreugd et al., 2025; Perera et al., 2016). Suggested mechanisms for the effects of light on well-being and mood include serotonin and dopamine production and changes in brain activity relevant to emotional functioning, for example in the amygdala (Campbell et al., 2024; Praschak-Rieder & Willeit, 2012).

One prominent example of light affecting well-being is bright light therapy, which is relatively successful in alleviating symptoms of mood disorders and sub-syndromal seasonal affective changes (see Perera et al., 2016, for a review and meta-analysis). Similarly, indoor lighting assimilated to the rhythm of natural sun light during the course of the day (so called dynamic lighting, including dawn and/or dusk simulations) was associated with better mood for older adults living with dementia (Bromundt et al., 2019). A recent meta-analysis reported a moderate effect of light exposure interventions on well-being (Landvreugd et al., 2025). The meta-analysis included a wide variety of different well-being outcomes and measures, with the most frequently reported ones being affect, and health, but also including measures of quality of life and life satisfaction. The results from light therapy and intervention research thus support the important role of light exposure in well-being.

While interventional studies that manipulate people's light exposure can more easily draw conclusions regarding causal effects of light exposure, this type of research lacks ecological validity. People are exposed to varying levels and types of light in their daily lives, some within and some outside their control (Biller et al., 2025), along with many other experiences. Ambulatory assessment research, combining objective measurement of people's light exposure with repeated self-assessments of well-being as they go about their daily lives, in turn, allows us to assess light exposure in the *real-world*, in *real-time*, and analyze how variability in light exposure is associated with variability in well-being *within persons* (Mehl & Conner, 2012).

However, there is relatively little research on effects of light on well-being in daily live and the findings are inconclusive, differing both for the same and across different outcomes. In a recent review which focused on associations of daily light exposure with sleep and mood (Böhmer et al., 2021), only one of two studies including light exposure and positive affect, observed that more light exposure predicted stronger positive affect (Figueiro et al., 2017; Rot et al., 2008). No significant associations between light exposure and negative affect were observed (Böhmer et al., 2021). However, in one study, people who self-reported higher lighting levels in the room in which they spent the majority of their time, also reported more positive affect and less stress or depression

(Figueiro et al., 2021). People who were generally exposed to more bright light at the office, further reported increased vitality and lower depressive symptoms (Figueiro et al., 2017). Although collected in daily life, these were cross-sectional findings on the between-person level. Extending this to the within-person level, exposure to more light in the previous hour was linked with increased vitality in daily life with effects of a similar size as effects of previous sleep, physical activity, or social contact (Smolders et al., 2013). At the same time, other studies did not observe associations between daily life light exposure and depressive symptoms (e.g., Jean-Louis et al., 2005; for review see Böhmer et al., 2021). Even the effect of light exposure on alertness which is relatively stable in experimental research (see Mu et al., 2022, for a meta-analysis), has not been observed consistently in daily life: In one recent study, the time people spent in light above a variety of different thresholds did not predict momentary alertness (Peeters et al., 2022). Nonetheless, experiencing brighter days and darker nights in daily life was associated with a lower incidence of several psychiatric disorders in a large panel study (Burns et al., 2022), pointing to potential long-term consequences of light exposure for mental well-being.

The previously discussed findings were based on general light exposure, without differentiating different light sources, but some research points to the particular relevance of natural daylight. Workers in offices with windows reported increased vitality (Boubekri et al., 2014) and people who reported spending between 1-2h per day outside reported less stress and more positive affect than people spending only 10-30 min outside (Figueiro et al., 2021). Similarly, when people self-reported more daylight in their current surroundings, they also reported better current mood, more energy, and less tension (Beute & de Kort, 2018). Furthermore, people reported higher daily PA (but not lower NA) on days with longer sensor-measured time spent above 1,000 lx per day (i.e., very likely under natural daylight; Shankman et al., 2025).

Despite some findings supporting an association of higher light exposure with higher well-being, including positive affect, vitality, and alertness, previous research suffered from several shortcomings, for example short assessment periods, the analysis of cross-sectional associations, and the methods and sensors used to measure light exposure (Böhmer et al., 2021). Short assessment periods limit the statistical power to identify potentially small effects and cross-sectional between-person associations do not necessarily reflect momentary within-person associations (Hamaker, 2012). Regarding light measurement, one potential limitation of previous research is sensor placement. For example, wrist-worn sensors, which have often been used in previous research (e.g., Gloor et al., 2018; Rot et al., 2008; Shankman et al., 2025), do not measure in the vertical plane (i.e., they do not align with the natural viewing direction) and they are likely to be covered by sleeves for substantial periods of time. Sensors worn near the eyes are preferable to wrist-worn devices, with devices worn on the chest providing the best trade-off between accuracy and usability (Aarts et al., 2017; Zauner et al., 2025). Additionally, with regards to recent developments in the assessment of non-visual light effects, the sensors need to allow a description of light exposure in terms of mEDI to accurately predict non-visual effects (Brown, 2020) which was not always possible in previous research depending on the sensors used (e.g., Shankman et al., 2025).

A further factor not sufficiently considered in previous research are the timeframes across which light exposure is measured and aggregated. Across different studies, the time windows considered for light exposure reach from at the same moment (Gloor et al., 2018), over 1 min (e.g., Didikoglu et al., 2023), 30 min (Peeters et al., 2022), 1 h (Smolders et al., 2013), the whole day (Shankman et al., 2025), up to several days (Burns et al., 2022). Only one recent study specifically considered different timeframes, analyzing how light exposure from the last minute up to the last eight hours predicted sleepiness: Light exposure aggregated over the last six hours had the strongest effect on sleepiness (Didikoglu et al., 2023). Similar analyses have not been reported for other well-being outcomes, leaving open the question across which time frames light exposure may impact on different well-being outcomes.

The Current Study

In the current study we aim to address several of these short-comings to analyse associations of temporally proximal light exposure with several different well-being outcomes in daily life. In this paper, we address RQ2 and Hypothesis 1 from our preregistration (https://osf.io/4m6e3/overview?view_only=bd17296468eb4091870abe165ac1bfb6). Further research questions and hypotheses focus on the description of light exposure in daily life (RQ1) and associations with sleep (RQ3 and H2); these will be addressed in separate manuscripts. As preregistered, we explore how different metrics of light exposure aggregated across different time periods predict PA, NA, vitality, and alertness. We test the hypothesis that light exposure that is more closely aligned with the recommendation of at least 250 lx mEDI during daytime will be associated with better well-being. Concretely, we focus on average levels of mEDI and percentage of time spent above the recommended level of 250 melanopic lx in the past 5, 60, and 180 minutes.

Methods

Transparency and Openness

In this article, we report how we determined our sample size, all data exclusions, all manipulations, and all measures that were included in the study. The analyses for this paper were preregistered. Analysis scripts and aggregated data used for the analyses are available online (https://osf.io/nwqfx/overview?view_only=6e67da972dbc44c2abe80ba161b94aa0). All software used is reported in the Supplementary Material. We follow the APA JARS.

Participants

For this study, we recruited a generally healthy sample of 30 younger (target age range 18 – 35 years old) and 30 older adults (target age range 60 to 80 years old). The planned sample size of n = 30 per group, was based on Zauner et al. (2023), who created a procedure to calculate statistical power and required sample size for wearable light-logging data. Their approach showed that for strong differences in light exposure patterns (i.e., winter vs. summer) even smaller samples are sufficient (n = 3-24). While we did not expect that differences between age groups are as strong as seasonal differences, the study was powered to detect group differences of d = 0.7.

Participants needed to own a smartphone compatible with the m-Path app to be able to participate. People could not participate when they were pregnant, engaged in shift work, had eye diseases or operations (e.g., glaucoma macular degeneration, diabetic retinopathy conditions, pseudophakic eyes) or psychological disorders (e.g., insomnia, depression, bipolar disorder, or generalized anxiety disorder). One person was excluded from the analyses because their light logger was set to a different sampling frequency (60 seconds instead of 10 seconds) due to a technical error. The analytical sample consisted of 30 younger adults between 19 and 32 years (*M* = 24.1, *SD* = 3.2, 47% women) and 29 older adults between 59 and 76 years (*M* = 67.4, *SD* = 5.16, 59% women).

Procedure

The study was approved by the ethics committee at the medical faculty of RWTH Aachen University (approval number EK 24-324). Data were collected between November 2024 and April 2025 in the region of Aachen, Germany. For every participant, the study started with an in-person onboarding session on a Monday during which they gave informed consent, filled out a baseline questionnaire, and enrolled for the study in the m-Path app (Mestdagh et al., 2023). Upon registration in the app, they received an example questionnaire to introduce the types of questions asked and familiarize them with the functionality of the app. Participants further received the wearable light logger to wear as pendant around their neck on top of any clothing (including jackets and scarves). They were instructed to take the pendant off before contact sports or whenever it could get wet (e.g., before showering). When participants took off the light logger during the day, they were instructed to place it inside a black bag which was recently validated as a useful method to identify non-wear periods (Guidolin, Zauner, et al., 2024). While participants were sleeping, they were asked to place it face up on a surface close to their head (e.g., a night stand).

Starting on Day 1 at noon and continuing through Day 10, participants received push notifications prompting them to fill out six short questionnaires (also referred to as beeps) per day. Participants reported on their current well-being, situation, and caffeine consumption in every beep. The first beep each morning additionally included questions on sleep the night before; it did not include alertness. The further questionnaires additionally included questions on the experience of stressors and uplifts. (For an overview of all assessed variables see https://osf.io/nwqfx/overview?view_only=6e67da972dbc44c2abe80ba161b94aa0)[1]

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[1] The larger study included further components that are not relevant for this paper: Participants underwent an extensive eye-exam during the onboarding session. Furthermore, following the ambulatory assessment phase, the study continued with an experimental laboratory component on Days 11 and 12 during which participants spent one day under bright and dim light respectively in counter-balanced order.

Participants received a notification for the morning questionnaire every hour starting at 06.00 until 09.00 h; it was available to be filled out until 10.00 h and participants were instructed to answer it as soon as possible after waking up. The four daily questionnaires were signal-contingent and semi-randomized: Notifications were randomized within four time-blocks (10.00 – 12.00 h; 12.30 – 14.30 h; 15.00 – 17.00 h; 17.30 – 19.30 h) and questionnaires expired one hour after the notification was sent. The evening questionnaire was first prompted at 21.00 h and every hour thereafter until midnight; it was available until 4.00 h and participants were instructed to fill it out shortly before going to sleep. Each of the questionnaires could only be filled out once.

For full participation in the study (baseline assessment, eye examination, ambulatory assessment, laboratory component) participants received 155€. They received a bonus of 20€ for completing at least 80% of the momentary assessments and an additional bonus of 20€ for completing at least 90% of the momentary assessments to incentivize adherence to the protocol. Overall, adherence to the protocol was relatively high with participants responding to 87.3% (SD = 13.0) of the short questionnaires.

Measurement

Light Exposure

The light logger (ActLumus, Condor Instruments, São Paulo, Brazil) continuously sampled information on participants' light exposure every 10 seconds using ten spectral channels. Based on the spectral distribution, the light logger calculates mEDI in lux. As preregistered, data from the light logger was considered missing when it showed 0 lx during the day; these values were recoded to NA during data preprocessing. We then used measurements selected based on the individual times participants filled out the short questionnaires in their daily life to calculate the metrics used in our analyses (see section "Analytic Strategy").

Current Light Sources

At each of the six daily assessments, participants reported on the primary light source in their current environment. They chose from the options *electric light indoors (e.g., LED, halogen, fluorescent), electric light outdoors (e.g., street lamp), daylight indoors (through windows), daylight* *outdoors (even in the shade), emissive displays (e.g., smartphone, laptop, etc.), darkness (indoors or outdoors), light from outside during sleep (e.g., sky glow, street lamps, etc.)*, similar to other current research (Guidolin, Aerts, et al., 2024). We created a new variable indicating whether the current primary light source was natural daylight (when the primary light source was reported as daylight indoors or daylight outdoors) vs. not (all other options).

Positive Affect

At each of the six daily assessments, participants reported their current positive affect by stating how much they currently felt each of the emotions *content, relaxed*, *happy,* and *energetic* (Neubauer & Grünert, 2025) on a seven-point scale from "*not at all"* to "*very much"*. We calculated participant's momentary PA as the mean of the four items. Internal consistency was $\omega^w = 0.77$, 95% CI [0.76, 0.79] at the within-person level and $\omega^b = 0.93$, 95% CI [0.89, 0.95] at the between-person level.

Negative Affect

At each of the six daily assessments, participants reported their current negative affect by stating how much they currently felt each of the emotions *anxious, sad, angry,* and *irritable* (Neubauer & Grünert, 2025) on a seven-point scale. We calculated participant's momentary NA as the mean of the four items. Internal consistency was $\omega^w = 0.63$, 95% CI [0.61, 0.65] at the within-person level and $\omega^b = 0.73$, 95% CI [0.57, 0.82] at the between-person level.

Vitality

At each of the six daily assessments, participants reported their momentary vitality using the five items of the German state-level version of the subjective vitality scale (SVS-G; Bertrams et al., 2020). Participants rated their agreement to statements such as "At this moment, I feel alive and vital." on a seven-point scale from "*does not apply*" to "*applies very much*". We calculated momentary vitality as the mean response the five items of the subjective vitality scale at each beep. Internal consistency was $\omega^w = 0.90$, 95% CI [0.90, 0.91] at the within-person level and $\omega^b = 0.90$, 95% CI [0.84, 0.93] at the between-person level.

Alertness

At five of the daily assessments (not in the morning questionnaire), participants reported their momentary alertness using the Karolinska sleepiness scale. They indicated their momentary alertness (vs. sleepiness) on a 10-point scale from “*extremely alert”* to *“extremely sleepy, great effort to keep awake”.* To ease interpretation, these values were recoded so higher values reflect higher alertness (rather than sleepiness) and adjusted to a seven-point scale by dividing values by 10 and multiplying by 7 to match the range of the scales used to assess PA, NA, and vitality.

Analytic Strategy

Because lux values are highly skewed, we worked with log-transformed data. Before the log-transformation, all values < 1 lx were recoded to 0.5 lx. As preregistered, we then calculated the mean light exposure in the 5, 60, and 180 minutes before each beep for each participant (these are referred to as the three aggregation windows). Similarly, we calculated how much of the time in the 5, 60, and 180 minutes before each beep (in %) people spent above the recommended daytime threshold of 250 melanopic lx. To separate within-person associations from stable between-person differences, we centered the resulting values on the participants’ average light exposure at this specific beep across the study before including them in the models. To illustrate, light exposure in the five minutes before beep 2 on day 1 for a participant would be centered on the average light exposure that this participant had in the five minutes before beep 2 across days 1-10. Additionally, we calculated participants average daytime light exposure (i.e., between waking up and going to sleep) across the whole study duration as a person-level variable.

We conducted separate multilevel models for each well-being outcome and each aggregation window. We included random intercepts and random slopes to allow mean levels of well-being and associations of light exposure and well-being to differ between participants. As pre-registered, when this led to convergence issues, we switched to fixed slopes. Only aggregation windows with less than 20% missing light exposure data for any given model were included in the analyses. For the 5 min aggregation window this means that only windows where at least 24 of the 30 possible measurements contained valid data (i.e., no 0 lx values) were included in the analyses. Depending on the aggregation window this resulted in 12.8–23.5 % of beeps being excluded. In each model, we controlled for time-of-day effects by including the beep number (1 – 6) as a factor (with beep 1 as reference category for PA, NA, and vitality and beep 2 as reference category for alertness). Additionally, we controlled for age-group because of known age differences in, e.g., affective functioning (Riediger & Rauers, 2014). As preregistered, we conducted further analyses controlling for weekday vs. weekend. Code and full results for all models can be found in the project's OSF-repository (https://osf.io/nwqfx/overview?view_only=6e67da972dbc44c2abe80ba161b94aa0).

Deviations from Preregistration

In the following, we delineate where we deviated from the pre-registration. The preregistration states the adjective *scared* as one of the NA items, when the more fitting English translation is *anxious*; we thus adapted this in the main text. For the analyses, we had preregistered using the geometric means of the momentary mEDI values across the different aggregation windows as predictors. However, the within-person distributions of the geometric means were highly problematic and showed extreme outliers which would have been problematic for model estimation. We therefore decided to use the arithmetic mean of the log-transformed mEDI values instead, as has been done in previous research (e.g., Didikoglu et al., 2023). Furthermore, we excluded aggregation windows with more than 20% missingness on the data from the light logger. We did not preregister how we would treat missing light data for the analyses. Lastly, we included the variable beep number (to control for time-of-day effects) and age group (to control for age differences in well-being) in all analyses, which was not pre-registered.

Results

Descriptives

Descriptive statistics and correlations for all variables of interest are reported in Table 1. The well-being measures were correlated in the expected direction both on the within- and the between-person level. Furthermore, the measures of light exposure across the different aggregation windows were highly positively correlated.

Light Intensity as a Predictor of Well-Being

When people experienced higher levels of mEDI in the 5, 60, and 180 minutes before a beep than usual for them at that time of day, they reported higher momentary vitality (b_5 = 0.142, 95% CI [0.064 – 0.221], b_{60} = 0. 164, 95% CI [0.072 – 0.256], b_{180} = 0. 159, 95% CI [0.056 – 0.263]) and alertness (b_5 = 0.167, 95% CI [0.097 – 0.236], b_{60} = 0. 181, 95% CI [0.089 – 0.273], b_{180} = 0. 188, 95% CI [0.086 – 0.290]), but not higher PA (b_5 = 0.040, 95% CI [-0.021 – 0.101], b_{60} = 0.054, 95% CI [-0.018 – 0.127],) or lower NA (b_5 = 0.013, 95% CI [-0.026 – 0.052], b_{60} = 0.006, 95% CI [-0.043 – 0.054], b_{180} = 0. 010, 95% CI [-0.052 – 0.071]), except for higher PA with higher levels of mEDI in the last 180 min (b_{180} = 0. 087, 95% CI [0.001 – 0.173]) The findings are visualized in the left panel of Figure 1.

Associations were controlled for time-of-day effects showing higher average PA and vitality during beeps 2-5 compared to beep 1 (see Supplementary Tables S1 - S3). Controlling for day of the week effects (weekday vs. weekend) did not change any of the conclusions, that is, significance and direction of the reported effects remained the same (see Supplementary Tables S4 - S6).

To better understand these results, we conducted further exploratory analyses. First, we separately analyzed associations of light exposure with high arousal PA (happy, energetic) and low arousal PA (content, relaxed). Results showed that brighter light exposure in the previous 5, 60, and 180 minutes predicted stronger high arousal PA (b_5 = 0. 073, 95% CI [0.005 – 0.140], b_{60} = 0. 095, 95% CI [0.014 – 0.176], b_{180} = 0. 133, 95% CI [0.035 – 0.232]), but not low arousal PA (b_5 = 0. 008, 95% CI [--0.057 – 0.073], b_{60} = 0. 014, 95% CI [-0.066 – 0.094], b_{180} = 0. 041, 95% CI [-0.053 – 0.136]). Because NA could not be differentiated into high and low arousal as clearly, we separately analyzed each NA item. There were no significant associations of light exposure in any aggregation window with any of the NA items. For full results from these analyses see Supplementary Tables S7 - S9.

We then analyzed whether including longer time windows of light exposure added explanatory value by comparing model fit when adding light exposure for the different aggregation periods to the same model one by one. We retained the random slope for light exposure in the previous 5 min and added fixed slopes for the further aggregation windows to ensure model parsimony and convergence. The results from likelihood ratio tests showed that for PA, the model including 180 min above 5 min and 60 min fit significantly better, $\chi2(1) = 5.14$, $p = .023$, the same was true for high arousal PA, $\chi2(1) = 5.22$, $p = .022$. For vitality and alertness, the model only including 5 min did not fit significantly worse than the extended models. The same was true for low arousal PA and NA. Full results for these models are reported in Supplementary Tables S10 - S15.

Because previous research has pointed to the particular relevance of natural daylight, we exploratorily considered the primary light source reported in the momentary assessments as a potential moderator in the association of light exposure in the previous five minutes with the different well-being outcomes. We included the binary variable 1 = natural daylight, 0 = other light sources in our models as an interaction effect with light exposure in the previous five minutes. The interaction effect was significant for PA and vitality. Simple slopes showed that the association of light exposure in the past five minutes with PA and vitality was only significant when daylight was the primary light source (PA: b = 0.087, 95% CI [0.009, 0.164], *p* = .028; vitality: b = 0.186, 95% CI [0.089, 0.283], *p* < .001), but not for other light sources (PA: b = -0.034, 95% CI [-0.120, 0.051], *p* = .432; vitality: b = 0.063, 95% CI [-0.043, 0.171], *p* = .243). This was not the case for alertness: The main effect of higher melanopic lx in the previous 5 minutes on higher alertness remained significant and there was no significant interaction effect. Simple slopes are displayed in Figure 2. Full results are reported in Supplementary Table S16.

As pre-registered, we further explored whether variability in light exposure was associated with the different aspects of well-being and added the standard deviation of melanopic lx in the previous 5, 60, and 180 min as an additional predictor. Higher variability in the past 5 min was associated with higher PA, vitality, and alertness; higher variability in the past 60 min was associated with higher vitality; and higher variability in the past 180 min was associated with higher PA and vitality. Results for these models are reported in Supplementary Tables S17 – S19.

Time above 250 lx melanopic EDI as a Predictor of Well-Being

To evaluate whether the recommendations for light levels above 250 melanopic lx apply to well-being in daily life, we analyzed whether a higher percentage of time spent above 250 melanopic lx in the past 5, 60, or 180min was associated with higher well-being. For these analyses, we focused on beeps 1 – 5 because beep 6 was supposed to be filled out shortly before going to bed and would thus fall into the evening period (three hours before bedtime) with lower recommended light levels.

In line with predictions, a higher percentage of time spent at light levels above 250 lx mEDI in the last 5, 60, and 180 minutes was associated with people reporting higher momentary PA (b_5 = 0. 167, 95% CI [0.049 – 0.285], b_{60} = 0. 213, 95% CI [0.048 – 0.378], b_{180} = 0. 301, 95% CI [0.082 – 0.519]), vitality (b_5 = 0. 234, 95% CI [0.084 – 0.384], b_{60} = 0. 362, 95% CI [0.169 – 0.556], b_{180} = 0. 461, 95% CI [0.227 – 0.695]), and alertness (b_5 = 0. 230, 95% CI [0.094 – 0.366], b_{60} = 0. 346, 95% CI [0.159 – 0.532], b_{180} = 0. 386, 95% CI [0.151 – 0.620]). More time spent at light levels above 250 lx mEDI was not associated with lower NA. These results are visualized in the right panel of Figure 1 und full model results are reported in Supplementary Tables S20 – S22. Controlling for weekend vs. weekday did not change the results; significance and direction of all reported effects remained the same (see Supplementary Tables S23 – S25).

We again analyzed the incremental explanatory value of including longer time windows, by comparing model fit when adding light exposure for the different aggregation windows one by one. The results from likelihood ratio tests showed that for PA, the model including the 180 min window above 5 min and 60 min fit significantly better, χ2(1) = 5.96, p = .015. For vitality, the model including the 60 min window fit better than the one only including the 5 min window, χ2(1) = 7.56, p = .006; including 180 min further improved model fit, χ2(1) = 5.81, p = .016. For alertness, the model including 60 min fit better than the one only including 5 min, χ2(1) = 5.81, p = .015, but further including 180 min did not improve model fit. Full results for these models are reported in Supplementary Tables S26 – S28.

We conducted further exploratory analyses comparing the effects of time above different thresholds (500, 750, and 1000 lx mEDI). Descriptively, more time spent at higher light levels had somewhat stronger effects on PA, especially when considering the longer time windows, with a ceiling reached at 750 lx mEDI. For vitality, time spent at light levels above 500 lx mEDI descriptively had the strongest effect; this also seemed the case for alertness when only considering the last 5 min, but not for longer aggregation windows. These results are illustrated in Supplementary Figure S1 and full results are reported in Supplementary Tables S29 – S40.

Discussion

In this study, both brighter overall levels of mEDI and longer time spent above 250 lx mEDI were associated with higher PA (especially high arousal PA), vitality, and alertness but not with lower NA. Additional analyses indicated that for PA and vitality this association may mainly exist for natural daylight, whereas the light source did not seem to matter for alertness, pointing to potentially different mechanisms. Generally, greater light exposure in the past 5, 60, and 180 min was associated with different aspects of well-being. The length of the aggregation window was differentially associated with the observed effect of light exposure, depending on the outcome considered.

Associations with well-being: More positive energy with more light?

The presented findings align with previous research showing that light exposure in the past minutes to hours is relevant for well-being – particularly supporting previous findings regarding associations with vitality (Figueiro et al., 2017; Smolders et al., 2013) and alertness (Didikoglu et al., 2023). Regarding PA, there were previously mixed findings (Böhmer et al., 2021; Figueiro et al., 2017; Rot et al., 2008), which the current study may help to better understand: We primarily found associations of light exposure with high arousal PA (feeling happy and energetic) but not with low arousal PA (feeling content and relaxed). When high and low arousal PA items are combined into one score, differential associations may thus be overlooked. Taken together, the current findings suggest that associations of light exposure with well-being may primarily be driven by energizing and alerting effects. In contrast, other aspects of light rather than brightness might be able to foster relaxation (e.g., light colour, Schweitzer et al., 2016). Whether there are light conditions in daily life that are more conducive to relaxation, contentment, or low arousal PA in general remains to be assessed.

In contrast to high arousal PA, NA did not seem to be associated with light exposure, which is in line with previous research, none of which observed associations with NA so far (see Böhmer et al., 2021; Shankman et al., 2025). Looking at discrete negative emotions did not change the conclusions regarding NA in this study – there were no significant associations with feeling anxious, sad, angry, or irritable. When considering the arousal level of these affective states, only sad may be considered as low arousal (Russell, 1980), but other typical low arousal NA items such as sluggish or downhearted were not included in the current study. Thus, while higher levels of lighting may not reduce medium to high arousal aspects of NA or sadness, one might speculate that the energizing effects of light as seen for PA and vitality could alleviate more low arousal aspects of NA. Along the same lines, the differential findings regarding high arousal PA and NA may also partially explain previous mixed results regarding associations of light exposure with depressive symptoms in daily life (Böhmer et al., 2021; Figueiro et al., 2017; Jean-Louis et al., 2005). While prolonged NA is one symptom of depression, so are a lack of energy, motivation, and concentration. Given the wide heterogeneity of depressive symptoms that are typically assessed in different scales (Fried, 2017), there is reasons to expect that different prior studies have captured slightly different aspects of depression that could be differentially associated with light exposure; i.e., scales focusing on NA may not have observed an association with light exposure, whereas those considering lack of energy or motivation might have.

In line with the recommendation that people should be exposed to at least 250 lx mEDI during the day, which was made for functioning more broadly, people reported higher high arousal PA, vitality, and alertness with more time spent above this threshold in the last 5, 60, and 180 min during the day. Exploratory analyses considering higher thresholds suggested that time spent at light levels above 500 or 750 lx mEDI may be even more predictive of stronger PA and vitality. Accordingly, these recommendations may need to be more thoroughly evaluated and potentially adapted for different outcomes, especially in daily life.

In additional analyses we furthermore considered variability in light exposure over the past 5, 60, and 180 min as a potential predictor of well-being. Surprisingly, following time windows with more variability in light levels (i.e., a higher SD), people partly reported higher PA, vitality, and alertness when controlling for mean levels. One potential reason for this may be contrast effects, i.e., brighter light may particularly predict higher well-being when there was a previous darker period which may be reflected in higher variability. Alternatively, more variability may also reflect more activity (light is less likely to vary while someone is sedentary at their desk compared to when they are “out and about”) which may in turn benefit well-being (Buecker et al., 2021; Jeckel & Sudeck, 2016). However, these findings should be considered exploratory and need to be corroborated by future research before drawing strong conclusions about the role of short-term variability in light exposure for well-being.

Time Windows: Are 5 Minutes Enough?

In the current study, we found little evidence for differential effects of light exposure during the past 5 minutes to the past 3 hours. Overall, it seemed that more light exposure in the previous minutes to hours was associated with higher PA, vitality, and alertness, regardless if light exposure had been aggregated across 5, 60 or 180 minutes. However, there seem to be some nuances adding onto this overall pattern. Specifically, there was some indication that for alertness longer time windows may be less relevant than for PA or vitality. Notably, this directly contradicts results from another recent study in which the explanatory value of light exposure linearly increased with longer aggregation windows, peaking at 6 hours (Didikoglu et al., 2023). One important methodological difference in this compared to our study was that participants mostly reported their alertness in the morning, whereas participants in our study reported alertness five times per day when prompted randomly from about 10:00 h in the morning until going to bed. These contrasting findings may thus suggest that there could be time-of-day factors at play. While we controlled for time-of-day differences in alertness by including time of day in our models, we did not consider whether different aggregation windows of light exposure may have more or less explanatory value at different times of day, that is whether a longer aggregation window may be more predictive of alertness in the morning compared to, e.g., the afternoon. The possibility of these differential time-of-day effects should be further considered in future research, also for associations of light with PA and vitality.

Differentiating Effects of Daylight vs. Other Light Sources

In line with other research pointing to the particular relevance of natural daylight for well-being (e.g., Boubekri et al., 2014; Shankman et al., 2025), we found that higher mEDI in the previous 5min was particularly associated with higher (high arousal) PA and vitality when daylight was the primary light source. However, the distinction daylight vs. other light sources did not modify associations with alertness. In our case, these analyses were based on the self-reported current primary light source which is why we only considered this for the 5 min aggregation window, during which it seems likely that the primary light source would have remained the same. The same assumption would not be reasonable for the longer aggregation windows (i.e., when looking at the previous hour, it could well be that people were, for example, both inside experiencing electric lighting and outside experiencing natural daylight). It seems plausible that the finding regarding the importance of daylight would extend to longer time windows and align with previous research showing that people reported higher PA on days when they spent more time above 1,000 lx mEDI (i.e., most likely under natural daylight conditions; Shankman et al., 2025). Nonetheless, this should be empirically analyzed for different time windows with well-being on the momentary (compared with the daily) level as well.

Causality

While it is tempting to subscribe to the notion of causal effects of light on well-being here (which do seem plausible given previous experimental research; Landvreugd et al., 2025; Perera et al., 2016) we cannot draw strong causal conclusions from the current findings for several reasons. First, light exposure is, to a certain extent, an active (health) behavior (Biller et al., 2024; Biller et al., 2025). This may also imply that people choose their light environment based on their current well-being. For example, it is possible that when someone feels low, they choose to stay inside and are thus exposed to lower levels of light because of their well-being (rather than the other way around). People’s active role in shaping their own light environment has thus far rarely been taken into account, yet it remains a crucial task for future research to identify predictors of purposeful light exposure behavior in daily life.

Second, confounding variables might account for (part of) the observed associations. For example, brighter light exposure occurs outdoors compared to indoors. However, brighter light is not the only aspect that differs between being outdoors and indoors: When outdoors, people are more likely to be physically active and they are more likely to be in nature and experience green spaces, both of which have been linked with well-being (Buecker et al., 2021; Houlden et al., 2018). Furthermore, when people are outdoors it is less likely that they are working and more likely that they are enjoying leisure time. Thus, conditions under which people are more likely to experience higher levels of light exposure may also be conditions under which they are more likely to report higher well-being, independent of light exposure. Some research has already observed additive (rather than compensatory) effects of light exposure and physical activity (Shankman et al., 2025) or exposure to nature (Beute & de Kort, 2018), but potential time-varying confounders should be kept in mind when interpreting the current findings.

One way to explicitly test causal effects of light exposure with high ecological validity would be a so-called micro-randomized controlled trial, for example in the context of a within-person encouragement design in which an intervention (i.e., an encouragement to show a certain behavior) is randomized to occur vs. not occur across time-points within individuals (Schmiedek & Neubauer, 2020). This design has successfully been applied to study causal effects of physical activity (prompting people to take short movement breaks) on cognitive function and mood (Giurgiu et al., 2024) and seems like a promising next step to evaluate causal effects of other health behaviors such as light exposure in daily life as well.

Strengths and Limitations

Despite several strengths of the current research such as the comparatively long assessment period of 10 days, up to six daily assessments of several different aspects of well-being, and the comprehensive measurement of light exposure, we also acknowledge its limitations.

People were instructed to take the light logger off whenever it could get wet or damaged (e.g., during contact sports) and placed it inside a black bag during those times. We therefore considered any periods with light values of 0 lx during people's individual waking hours as missing and any of our aggregation windows with more than 20% missingness were excluded from analyses, which affected up to 23.4% of data points. This data reduction compromises statistical power and could also lead to systematically missing observations that could limit the generalizability of our findings. Additionally, it is possible that the light logger was occasionally covered by clothing such as scarves or jackets and that overall levels of light exposure could thus have been underestimated.

There are several aspects of light exposure that could explain its potential effects; in this study, we considered both intensity and duration which is a good starting point. One factor that we only considered indirectly is the timing of light exposure, i.e., when during the day people were exposed to which level of light for how long. We controlled for potential time-of-day differences in the well-being outcomes by including the beep number, but this is a rather rough measure. Future research could model this aspect in more detail, ideally taking into account individual differences in circadian phase (e.g., by considering chronotype).

Constraints on Generality

Data were collected between November and early April (late autumn to early spring) in Germany; during this time of year the availability of natural daylight varies between 8 – 13 hours per day. First evidence points to differential effects of light exposure in different seasons for sleep (e.g., Peeters et al., 2022) and this might also apply to well-being in daily life. However, the amount of data across autumn and spring does not afford us sufficient power to assess seasonal differences in the current study. Thus, the current findings might not generalize across seasons (i.e., to summer) or regions with different daylight patterns (e.g., Scandinavia).

Additionally, the data in this study stem from a sample of younger and older adults and we found significant associations of light exposure with well-being using the whole sample. Because of the inclusion criteria, the older adults in the sample were generally healthy and it is unclear whether the findings would generalize to more vulnerable populations.

Conclusion

The present study showed that exposure to higher levels of melanopic lx and longer times spent above the recommended threshold of 250 lx mEDI during the day were associated with better concurrent well-being, specifically higher high-arousal PA, vitality, and alertness (but not lower NA). This pattern of results may suggest mainly energizing and activating effects of light exposure in the past minutes to hours. Exploratory analyses suggested that time above thresholds higher than 250 lx mEDI may be more predictive for better functioning which should be considered in more detail in future research. Experimental studies in daily life are needed to corroborate causal effect of light exposure on well-being. Light exposure behavior might lend itself as a promising target for interventions to increase mental and physical health in daily life.

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Table 1

Descriptive Statistics, within-person correlations (above the diagonal), and between-person correlations (below the diagnonal).

		mean	SD	iSD	ICC	1	2	3	4	5	6	7	8	9	10	11
1	PA	4.73	0.88	0.77	0.55	-	**-0.406**	**0.665**	**0.368**	**0.158**	**0.182**	**0.188**	**0.123**	**0.142**	**0.162**	-
2	NA	1.53	0.65	0.42	0.58	**-0.44**	-	**-0.190**	-0.038	0.018	0.026	0.027	0.002	0.019	0.011	-
3	Vitality	4.46	0.91	1.04	0.42	**0.920**	**-0.374**	-	**0.685**	**0.309**	**0.318**	**0.276**	**0.214**	**0.261**	**0.268**	-
4	Alertness	5.24	0.54	1.11	0.17	**0.584**	**-0.274**	**0.645**	-	**0.354**	**0.365**	**0.339**	**0.227**	**0.276**	**0.283**	-
5	MEDI5	1.44	0.28	0.88	0.07	0.144	-0.128	0.108	0.015	-	**0.780**	**0.612**	**0.716**	**0.624**	**0.548**	-
6	MEDI60	1.36	0.25	0.92	0.05	0.186	-0.176	0.169	-0.011	**0.932**	-	**0.877**	**0.541**	**0.747**	**0.704**	-
7	MEDI180	1.34	0.25	0.91	0.05	0.248	-0.246	0.231	0.073	**0.902**	**0.956**	-	**0.415**	**0.624**	**0.760**	-
8	perc >250 5min	0.14	0.08	0.27	0.05	0.064	-0.130	0.068	-0.029	**0.755**	**0.690**	**0.724**	-	**0.722**	**0.561**	-
9	perc >250 60min	0.15	0.09	0.24	0.08	0.121	-0.246	0.135	0.025	**0.736**	**0.765**	**0.801**	**0.926**	-	**0.832**	-
10	perc >250 180min	0.15	0.09	0.20	0.13	0.169	**-0.292**	0.185	0.095	**0.717**	**0.734**	**0.804**	**0.897**	**0.977**	-	-
11	Mean Daily MEDI	1.64	0.27	-	-	**0.281**	**-0.288**	**0.290**	0.146	**0.817**	**0.841**	**0.899**	**0.718**	**0.792**	**0.823**	-
12	agegroup	0.47	-	-	-	**0.416**	**-0.425**	**0.468**	**0.396**	**0.315**	**0.260**	**0.350**	**0.396**	**0.450**	**0.501**	**0.409**

Note. PA = positive affect. NA = negative affect. MEDI5/60/180 = mean log10-transformed mEDI in the 5, 60, and 180 min preceding a beep. Mean Daily MEDI = mean log10-transformed mEDI during waking hours. Alertness was first reverse coded from the 10-point Karolinska Sleepiness Scale so higher values reflect higher alertness and then recoded by dividing values by 10 and multiplying by 7 to match the scales used to assess PA, NA, and vitality. Age group: 0 = younger adult, 1 = older adult. Correlations printed in **bold** indicate p < .05

Figure 1

Within-person associations of average melanopic lx and time spent above 250 melanopic lx in the previous 5, 60, and 180 minutes with different well-being outcomes

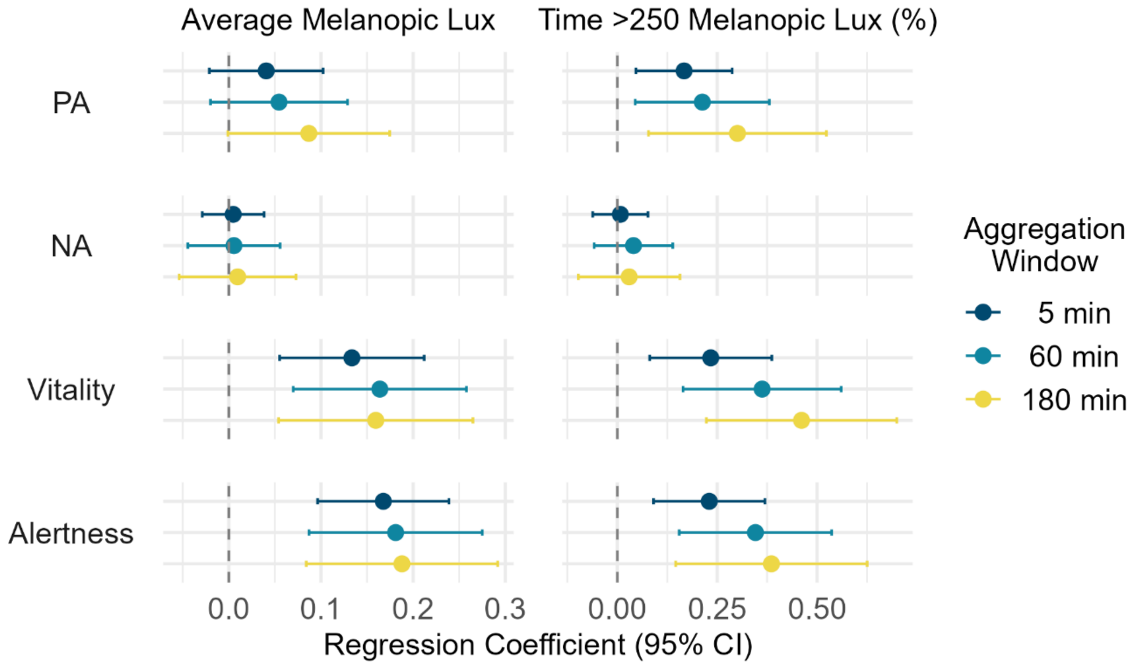

Figure 2

Simple Slopes for the Associations of Melanopic EDI levels in the Previous 5 min When Daylight was vs. was not the Primary Light Source