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Shedding light on light exposure in elderly with intellectual disabilities

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Abstract

Background Light exposure affects mood and sleep regulation. Sleep problems and mood complaints are common in elderly with intellectual disabilities (ID) living in care facilities. Insufficient light exposure is hypothesised to contribute to the high prevalence of these problems. The current study is the first to describe the personal light exposure pattern during the waking day in elderly with ID.

Methods The study sample consists of 82 elderly with ID (aged 62.3 ± 9.4 years) living in 16 residential homes of three care organisations in the Netherlands. Personal light exposure was measured continuously for 7–10 days using a HOBO data logger light sensor, measuring illuminance at chest height. Participants wore a wrist-worn accelerometer (Actiwatch or Geneactiv) to indicate the bedtimes to determine the waking day.

Results The variation in illuminance is small during the waking day. Elderly with ID spend most of their waking day (mean duration = 14:32:43 h) in dim light (1–500 lux) environment and spend a median of 32 min in light > 1000 lux. Within participants, the threshold associated with better sleep (>50 min of light > 1000 lux) was reached for 34% of the days, and the threshold associated with less depressive symptoms (>30 min of light > 1000 lux) was reached in 46% of the days. Exposure > 1000 lux was lower during weekends than during weekdays.

Conclusion Elderly with ID spend most of their waking day in low light levels and did not meet the proposed values associated with better sleep and mood. Given the importance of adequate light exposure for regulation of sleep and mood, and the prevalence of sleep and mood problems in elderly with ID, the current study suggests that the lit environment for this already frail population should be given more attention.

Keywords aged, daylight, mood, photoperiod, residential facilities, sleep

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Introduction

Light is as important to perceive the world, as it is to regulate human physiology and behaviour. Daylight is the strongest time cue for the circadian rhythm (Duffy *et al.* 1996), a rhythm of about 24 h apparent in most human physiological processes and behaviour. Examples of processes and behaviours with a circadian rhythm are the sleep–wake rhythm, mood and performance (Minors and Waterhouse 1981). The right amount of ocular light exposure and timing of the light exposure is essential for synchronisation of the circadian rhythm. Insufficient ambient light or wrongly timed light exposure pushes the internal circadian rhythm out of sync with the external day–night rhythm, suggested to be associated with sleep and mood complaints (Luik *et al.* 2015).

In the general population, exposure to high illuminances is associated with positive affect (aan het Rot *et al.* 2008), less depressive symptoms (Espiritu *et al.* 1994; Figueiro *et al.* 2017), less sleep disturbances and overall better emotional well-being and quality of life (Grandner *et al.* 2006). People who were exposed to at least 30 minutes of illuminances above 1,000 lux on a daily basis, experienced fewer depressive symptoms compared to people exposed to less illumination (Espiritu *et al.* 1994). Elderly who were exposed to at least 50 minutes of light >1,000 lux per day, slept more efficient (Aarts *et al.* 2018). Beneficial effects of light exposure on health are evidenced by the effect of bright light therapy in the treatment of mood and sleep problems (Golden *et al.* 2005; Van Maanen *et al.* 2016).

In elderly with intellectual disabilities (ID), the prevalence of sleep problems is 72% (van de Wouw *et al.* 2013a), and the prevalence of depressive symptoms is 16.8% (Hermans *et al.* 2013). Despite the growing knowledge about the effects of light exposure on sleep and mood, care organisations for people with ID are often poorly lit. Jelluma *et al.* (2012) compared the lighting in these care organisations to the European lighting guideline for safety and optimal visual functioning in the working environment (EN 12464-1:2003). It was concluded that lighting in care facilities for people with ID reached the recommendations from the guideline only in 3.3% to 6.5% of the measurement (Jelluma *et al.* 2012). Jelluma *et al.* (2012) measured illumination within the living space in the context of the visual performance. However, in the context of regulation of circadian rhythms, measuring personal light exposure directly on the residents is needed as the effects of insufficient lighting to trigger the biological system in the living environment can be compensated by light exposure outside the living environment.

The current study aims to describe the continuously measured personal light exposure pattern during the waking day in elderly with ID living in care facilities. In addition, we explore whether elderly with ID are exposed to light levels associated with better mood (30 min > 1000 lux daily) and sleep (50 min > 1000 lux daily). With this study, we pave the way for further research on insufficient light exposure as a possible factor in the development of depression and sleep problems in elderly with ID.

Methods

Study design and setting

The data presented here consist of data collected during two studies. The first study assessed the light exposure in elderly with ID and was conducted between October 2015 and April 2016. The second study was an intervention study on the effect of ambient light on circadian sleep–wake rhythm, sleep and mood in elderly with ID and was conducted between October 2017 and June 2018. Of this latter study, only data on personal light exposure during the first baseline measurement that took place between October and December 2017 were used.

Data of both studies were used to construct a data set that follows a cross-sectional research design. The data were collected within three care organisations (Middin, ASVZ and SWZ) in collaboration with our department. The three care organisations service approximately 12 200 clients with borderline to profound ID in the Netherlands.

Participants were recruited from group homes (central residential setting or community-based home) for elderly with ID. Living in these group homes, clients each have their own bedroom or apartment. Meals are consumed in the communal living area. Some clients take part in in-home activities during the day or go to day care facilities or other residencies. In the first study, clients were recruited from 14 group homes: 10 of Middin, 3 of

SWZ and 1 of ASVZ. For the second study, clients were recruited from six group homes of Middin; of which four homes also participated in the first study (duplicate inclusions were excluded). A total of approximately 220 clients lived in these 16 residential homes.

Inclusion criteria

Inclusion criteria for the first study were (1) aged 50 years or older; (2) mild, moderate, severe or profound ID and (3) living in one of the 16 selected residential homes for people with ID. Clients known to be seriously/terminally ill or not able to appropriately handle the light measurement instruments used in this study were excluded from participation. No further exclusion criteria were applied.

Two alterations were made in the inclusion criteria of the second study; first, we lowered the minimum age to 40 years in order to reflect the population of group homes better. Second, in order to guarantee exposure to the intervention studied in the second study, the following criterion was added: residents were eligible to participate if they spend at least 1 h daily in the central living room, of which a minimum of 30 min between 07.00 h and noon.

Ethical approval and informed consent procedure

The Medical Ethical Committee of the Erasmus Medical Center Rotterdam made an exemption for a comprehensive application for both studies (MEC-2015-472 and MEC-2017-467). In both studies, based on the indication of the behavioural therapist of competence to give consent, either the clients or their representative signed informed consent.

Measurements

Waking day

Waking day was determined using actigraphic estimates of bedtimes and get-up times. In both studies, participants wore a watch-like actigraphy device designed to measure sleep and wakefulness based on the amount of movement activity. In study 1, participants wore the Actiwatch 2 (Mini Mitter, Respironics Inc., Bend, Oregon, USA), and in study 2, the Geneactiv (Activinsights, Kimbolton, UK). The Actiwatch 2 was found to be valid and reliable to use in elderly with ID (van de Wouw *et al.* 2013b). The Geneactiv was not validated in elderly with ID but was found to be valid and reliable in adults from the general population (Esliger *et al.* 2011). Data from both accelerometers are well comparable (te Lindert and Van Someren 2013). The Actiwatch was set to sum activity counts for 1-min epochs and the high sensitivity setting (20 counts per epoch), the Geneactiv was set to measure activity in 100 Hz. Raw data from the accelerometers were analysed to calculate the bedtimes using the Actant – Activity Analysis Toolbox (te Lindert and Van Someren 2013).

Three timeframes were defined: 'Waking day' as the period between final wake time and sleep onset time, 'Morning' as the 4 h after wake time and 'Evening' as the 4 h prior to sleep onset time.

Light exposure

To measure personal daily light exposure, participants wore a light sensor (HOBO data logger, Onset, New England, USA) on a necklace. The light sensor measured illuminance in lux in 1-min epochs. For reference, horizontal illuminance in a restaurant is about 20 lux, at home around 50 lux and offices are between 300 and 1000 lux depending on whether and where the windows are located. Outdoor horizontal illuminances are over 3000 lux on a cloudy day and can reach up to 100 000 lux on a sunny day.

As the light sensor is good at detecting relative change in illuminances, but not necessarily for absolute measurement of illuminances (Onset Computer Corporation 2018), each HOBO data logger was calibrated to sunlight using a calibrated illuminance meter (Hagner E4X, Solna, Sweden). This calibration provided an individual calibration factor for each HOBO, which was used to correct the measured data.

Zero-values in illuminance during the waking day were considered a result of the light sensor being covered with clothing. Zero-values were not random, as the chance of the light sensor being covered would increase if the participant was outside wearing a jacket over the light sensor. Therefore, zero-values during the day were interpreted as missing values.

In order to reduce the impact of a single minute of extreme illuminances (i.e. >10 000 lux), the illuminance in lux was logarithmical transformed to illuminance in log lux.

Demographics and health status

Besides registration of sex and age, the level of ID was obtained from behavioural therapists' record and was classified as borderline (IQ 70–85), mild (IQ 55–70), moderate (IQ 35–55), severe (IQ 25–35) or profound (IQ < 25). Professional caregivers filled out questionnaires on the activities of daily living (ADL) and mobility of the participant. Basic ADL was assessed with the Barthel Index (Mahoney and Barthel 1965). The Barthel Index consists of 10 items (e.g. feeding, dressing and toilet use), and the total score ranges from 0, completely dependent, to 20, completely independent. Psychometric properties (validity, test–retest reliability, sensitivity and clinical utility) of the Barthel index are good (Gresham *et al.* 1980; Wade and Hewer 1987; Wade and Collin 1988; Green *et al.* 2001).

Instrumental ADL (IADL) were assessed with the Lawton index (Lawton and Brody 1969), consisting of eight items (e.g. telephone use, food preparation and finances). The total Lawton score ranges from 8 (completely dependent) to 33 (completely independent). Based on validation studies in hospitalised older adults (Buurman *et al.* 2011) and older adults with dementia (Albert *et al.* 2006), it is considered a suitable instrument to use in elderly with ID.

Professional caregivers provided information about the mobility of participants inside the house, at work or school, and outside in a protected and unprotected area. The given answers were then converted into 'independent', 'with support' or 'wheelchair' (Oppewal *et al.* 2014).

Procedure

In the first study, participants were instructed to wear the light sensor and accelerometer for 10 consecutive days; in the second study, they wore the instruments seven consecutive days.

The light sensor was worn as a necklace on the chest between waking up in the morning and bedtime. Participants were instructed to wear the light sensor over their clothing; they were assisted in doing so by their caregivers. The accelerometer was worn on the non-dominant wrist. Participants did not receive compensation for their participation.

Statistical analyses

Analyses were performed with the Statistical Package for Social Sciences (SPSS) Version 25 (IBM Corporation, New York).

Selection of participants

In case of overlapping participants in the two studies, data of the first measurement that provided raw light exposure data were included in this data set.

Missing values

Following previous studies (Goulet *et al.* 2007), only timeframes with <25% missing data were included in the present analyses to present the most representative and reliable data.

Demographics and health status

Demographics of participants that did and did not provide valid data (at least one timeframe with <25% missing values) were compared using independent *t*-tests for continues variables, and χ^2 tests for categorical variables. For participants with valid data, demographics and light exposure between the two studies were compared using independent *t*-tests for continues variables and χ^2 tests for categorical variables.

Illuminance pattern

In participants who provided at least one waking day with valid data, the average illuminance (log lux) per minute over all valid waking days was calculated, which was used to calculate the average illuminance per hour. Next, we averaged the illuminance per hour over all participants. Illuminance in log lux was converted back to lux before the graph was created.

Average illuminance during timeframes

Average illuminance (log lux) per timeframe (waking day, morning and evening) was calculated, and possible differences between illuminance per timeframe were studied using a one-way analysis of variance (ANOVA). Log lux was transformed to lux for presentational purposes.

Categorised illuminances during timeframes

In participants who provided at least one timeframe (waking day, morning or evening) with valid data, the minutes spend at each illuminance category (1–100, 101–500, 501–1000 and >1000 lux) were summed. As data were not normally distributed, for each timeframe, the median and interquartile range of minutes spend in each category are presented.

Light exposure, level of intellectual disabilities and level of independency

Differences in average light exposure and illuminance categories in all timeframes over level of ID and level of independency (ADL, IADL and mobility) were tested. Regression analyses were used for the continuous outcomes Barthel scores and Lawton scores, and one-way independent ANOVAs were used for categorical outcomes level of ID and mobility. Analyses of light exposure and demographics during the waking day were corrected for duration of the waking day.

Exposure thresholds associated with sleep and mood

We calculated per participant the percentage of waking days that the threshold of 50 min >1000 lux was met, which was found to be associated with better sleep efficiency in elderly (Aarts *et al.* 2018). Percentage of days the threshold was met was averaged over all participants. We studied the threshold of at least 30 min of light exposure > 1000 lux, which was associated with less depressive symptoms (Espiritu *et al.* 1994), in the same manner as the threshold for sleep efficiency.

Illuminance during week and months

Average log-transformed illuminance per timeframe for week and weekend days were compared using an independent *t*-test. Time spend in each category for waking day during week and weekend days were compared using multivariate general linear model (GLM), correcting for duration of the waking day. Light exposure categories for morning and evening during week and weekends days were compared using one-way independent ANOVAs. The amount of timeframes that met the prespecified thresholds related to sleep efficiency and depressive symptoms during the week and weekend were compared using χ^2 tests. Light exposure >1000 lux during the waking day over months was compared using multivariate GLM, correcting for duration of the waking day. Light exposure >1000 lux for morning and evening over months was compared using GLM.

Results

Demographics and health status

Inclusion of participants and selection of data is shown in Fig. 1. A total of 48 women and 34 men participated, with an average age of 62.3 years (SD = 9.4 years) (Table 1). Participants with and without valid data did not differ based on age, sex, level of ID and mobility. Participants without data had a higher ability to perform basic ADL ($t(77) = 2.004$, $P = 0.049$).

Participants with data from the two studies did not differ based on age, sex, basic ADL and mobility (Table S4). Participants in the second study had a lower ability to perform instrumental ADL ($t(44) = -5.58206$, $P = 0.000$). Data on level of ID were missing for most of the participants in the first study. The studies did not differ based on the amount of valid data each participant provided (study 1: 4.05 waking days, study 2: 2.7 waking days, $P > 0.10$). Studies did not differ based on the average illuminance over the timeframes and illuminance in categories for waking day and evening. In the second study, mornings had more missing values (study 1; mdn 20 min, study 2; mdn 31 min, $P = 0.02$) and participants spend less time in >1000 lux during the morning (study 1; mdn 8 min, study 2; mdn 2 min, $P = 0.03$).

On average, participants provided illuminance data of 2.40 ± 2.58 waking days, 3.21 ± 2.47 mornings and 2.00 ± 2.41 evenings. Sleep onset time was on average 22:01:15 ± 01:12:49, and final wake time was 8:09:53 ± 01:16:23. The duration of a waking day was on average 14:32:43 h ± 02:39:11 h.

Light exposure, level of intellectual disabilities and level of independency

None of the light exposure outcomes were associated with level of ID and (instrumental) ADL. Participants who need support to be mobile are exposed to 56 min less of light >1000 lux ($P = 0.025$) and 209 min more

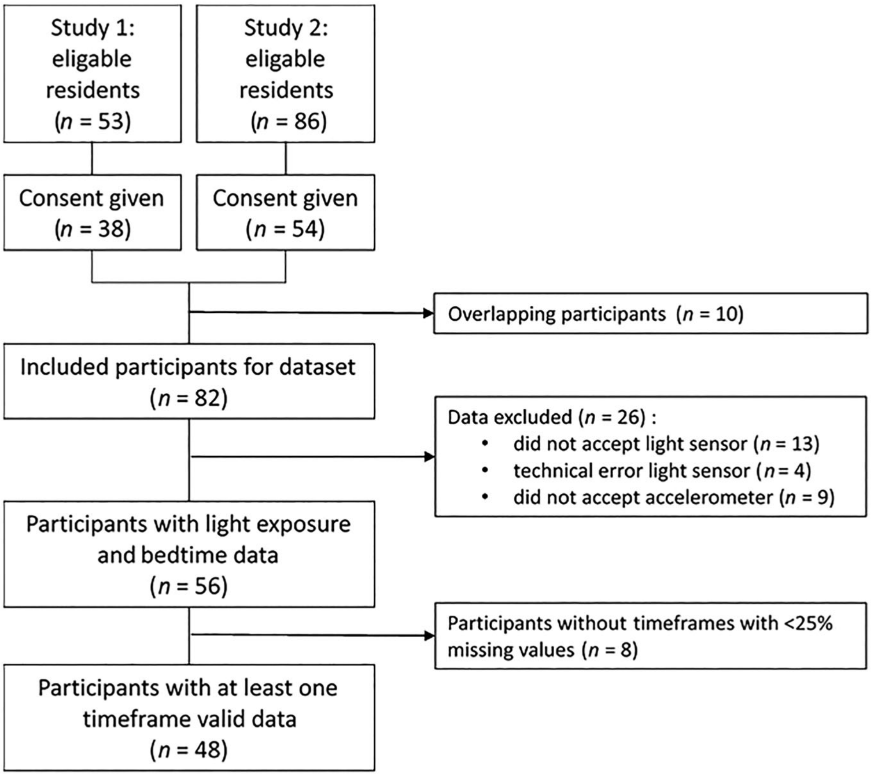

FIGURE 1. Flowchart inclusion of participants and selection of data.

Table 1 Participant characteristics of the total study group, comparison of participants with and without valid accelerometer and light exposure data for the timeframe analyses

Characteristic		Overall	%	Participants with valid data	Participants without valid data	*P*
N		82		48	34	
Sex, *n*	Female	48	59	29	19	0.68
	Male	34	41	19	15	
Age in years, mean (SD)		62.28 (9.4)		60.98 (9.16)	63.97 (9.83)	0.13
Level of ID, *n*	Mild	12	14.6	9	3	0.08
	Moderate	30	36.6	13	17	
	Severe	1	1.2	0	1	
	Unknown	39	47.6	26	13	
Barthel score, mean (SD)		13.82 (6.0)		12.69 (6.31)	15.40 (5.35)	0.049*
Lawton score, mean (SD)		8.22 (5.75)		7.26 (6.31)	9.72 (4.16)	0.051
Mobility, *n*	Independent	53	64.6	30	23	0.20
	Support	10	12.2	4	6	
	Wheelchair	16	19.5	12	4	
	Missing	3	3.7			

*Independent *t*-test for continues variables, χ^2 test for categorical variables, significance at *P* = 0.05.

light of 501–1000 lux (*P* = 0.000) during the waking day, of which 62 min during the morning (*P* = 0.000), than independently mobile participants. Despite the difference in distribution of light exposure over categories, average light exposure in lux did not differ over the mobility categories.

Illuminance pattern

In Fig. 2, the illuminance pattern of the waking day of the participants is shown. Between 06.00 and 07.00 h, there was a dip in illuminance. Further inspection of the data showed that the higher values around 06.00 h are due to four participants that woke up early and were exposed to illuminances between 300 and 500 lux. Around 07.00 h, other participants woke up and were exposed to lower illuminances, which explains the drop in average illuminances around that time.

The plateau of illuminance was between 11.00 and 14.00 h; after 14.00 h, the illuminance slowly decreased to a dip around dinner at 17.00 h. After dinner time, the illuminance increased again up till 22.00 h, which is explained by six participants with exposure to illuminance >200 lux after 21.00 h.

Average illuminance during timeframes

The average illuminance during the waking day was 155 ± 1 lux (mean ± SD). *Post hoc* analyses showed that average illuminance during the morning (166 ± 1 lux) was higher than during the evening (115 ± 1 lux) ($P = 0.006$).

Categorised illuminance during timeframes

During waking days, the median time spend in illuminances between 1 and 100 lux was 275 min (32%), followed by 274 min (32%) spend in 101–500 lux. The median time spend in >1000 lux during the waking day was 32 min (4%), of which 4.50 min during the morning. During the evening, participants spend a median of 94.50 min time in a dim light (1–100 lux) environment. During the afternoon, the participants were exposed the longest amount of time to light >1000 lux (Table 2).

Exposure thresholds associated with sleep and mood

Of 33 participants, we got valid data of at least one waking day. Within participants, the threshold associated with better sleep (>50 min of light >1000 lux) is reached for 34% of the days, the threshold associated with less depressive symptoms (>30 min of light >1000 lux) was reached in 46% of the days (Table 3).

Fifteen participants did not reach the threshold for sleep on any of the days, the remaining 16 participants reached the threshold for 61% (range 25–100%) of their days. Three participants reached the threshold for sleep every single day. With regard to mood, 10 participants did not reach the threshold on any of the days, and the remaining 23 participants reached the threshold for 63% (range 11–100%) of the days. Eight participants reached the threshold for mood every day.

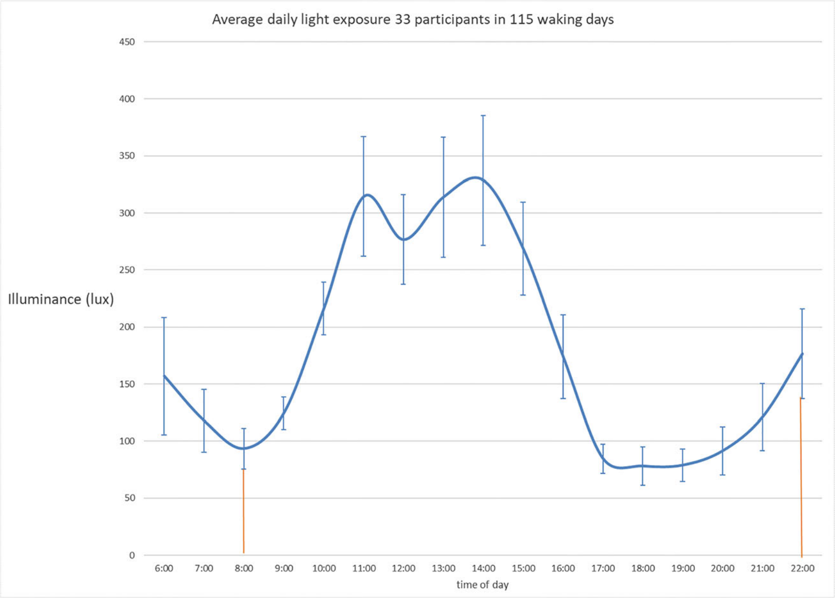

FIGURE 2. The personal illuminance pattern in lux of the waking day (06.00–22.00 h) of 33 participants between October 2015 to April 2016 and October to December 2017. Mean light exposure data for each hour were averaged per subject and then average across subjects. Error bars indicate the 95% confidence intervals of mean hourly light exposure. The vertical lines indicate average get-up time and bedtime.

Table 2 Minutes of illuminance in categories 1–100, 101–500, 501–1000 and >1000 lux and missing data during timeframes waking day, morning and evening with <25% missing values of 48 participants

Timeframe	Participants with valid data	Time frames	Minutes per timeframe	Average lux	1–100 lux	101–500 lux	501–1000 lux	>1000 lux	Missing data
	Count	Count	Median (IQR)	Mean (SD)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR) (%)
Waking day	33	115	860 (767–960)	155 (2)	275.00 (181.00–358.00)	274.00 (195.00–348.00)	75.00 (21.00–148.00)	32.00 (4.00–105.00)	136.00 (85.00–185.00) 15.81%
Morning	43	154	240 (240–240)	166 (2)	72.00 (43.75–110.75)	79.00 (53.75–113.00)	16.00 (4.00–44.25)	4.50 (0.00–23.00)	23.50 (9.00–40.00) 9.79%
Evening	36	96	240 (240–240)	115 (3)	94.50 (37.00–168.25)	59.50 (12.25–107.00)	1 (0.00–35.25)	1.00 (0.00–1.75)	30.50 (14.50–49.75) 12.7%

Illuminance during week and months

Mean illuminance during the waking day during the week was higher (173.28 ± 1.90 lux) than during the weekend (120.23 ± 1.9 lux, $t(113) = 2.962$, $P = 0.004$). When corrected for duration of the waking day, participants spend significantly less time in light >1000 lux during the weekend than during the week [week; mdn = 50 min (5.6%), weekend; mdn = 5.5 min (0.7%), $F_2 = 6.43$, $P = 0.002$]. During the weekend 18.5% of the waking days reached >50 min of light >1000 lux, compared to 50.6% during the week ($X^2(1, N = 115) = 11.01$, $P = 0.001$). During the weekend, 28.9% of the waking days met the threshold of over 30 min of light >1000 lux, compared to 62.3% during the week ($X^2(1, N = 115) = 11.355$, $P = 0.001$) (Tables S5 and S6).

Light exposure >1000 lux during January differed from the other months. *Post hoc* analyses with Sidak correction showed that light exposure to >1000 was significantly lower during January ($M = 14.42$ min, SD = 23.77 min, $F_5 = 4.38$, $P = 0.001$). No differences in exposure to >1000 lux were seen for timeframes morning and evening.

Discussion

The current study is the first to focus on personal daily light exposure as a possible factor in the development of sleep and depressive symptoms in elderly with ID living in a group home facility. Measuring light exposure seemed challenging, resulting in a large amount of missing values; thus, the results should be interpreted with some care. We found that the average illuminance in elderly with ID was 155 lux, and the illuminance pattern varied little over the day. The range of illuminance during the waking day was between 78 and 328 lux. In healthy elderly from the general population, this range during the waking day was 10 to 982 lux (Scheuermaier *et al.* 2010), indicating that the average illuminance during the day in elderly with ID is low.

The higher illuminances in the early morning and during the evening seen in some of the elderly with ID are thought to be caused by the lighting in the apartments of some participants. The dip of 50 lux around lunch time is interpreted as participants possibly leaning over to the table during lunch or the light sensor being covered by a bib. The dip in

Table 3 Exposure thresholds associated with sleep and mood for 33 participants with at least one valid waking day

Variable	Sleep (>50 min of >1000 lux per waking day)	Mood (>30 min of >1000 lux per waking day)
Percentage of days threshold was met	34%	46%
Participants met threshold for		
None of the days	15 (45%)	10 (30%)
≥ 1% of the days	18 (55%)	23 (70%)
≥ 25% of the days	17 (52%)	21 (64%)
≥ 50% of the days	13 (39%)	17 (52%)
≥ 75% of the days	7 (21%)	12 (36%)
100% of the days	3 (9%)	8 (24%)

Percentages of days that met thresholds within participants.

illuminance after 14.00 h might be because of the participants coming home from their daily activities were light exposure might have been higher.

Elderly with ID spent most of their waking day in indoor levels of light, which is comparable with the healthy general population of all ages (Savides *et al.* 1986; Espiritu *et al.* 1994; Hebert *et al.* 1998; Jean-Louis *et al.* 2000). Participants were exposed to a median of 32 min of light >1000 lux. Average illuminances above 1000 lux in adults from the general population ranges between 58 and 105 min per waking day (Espiritu *et al.* 1994; Kawinska *et al.* 2005; aan het Rot *et al.* 2008; Hubalek *et al.* 2010; Crowley *et al.* 2015). Independently living elderly were exposed to 65 min (Aarts *et al.* 2006) to approximately 2 h (Scheuermaier *et al.* 2010) of light levels above 1000 lux. Studies in clinical populations showed that patients with dementia in nursing homes were exposed for 10.5 min (Ancoli-Israel *et al.* 2003), and institutionalised elderly with schizophrenia 77 min a day to light >1000 lux (Martin *et al.* 2005). Elderly with ID living in group homes, like other groups in care facilities, were exposed to less light >1000 lux compared to the general population.

Elderly with ID were mostly exposed to light >1000 lux during the afternoon. For a beneficial effect on health, the amount of light exposure as well as the timing of the exposure is essential. With light exposure during the day, the suprachiasmatic nucleus becomes less sensitive for light exposure (Chang *et al.* 2011). Thus, bright light therapy as treatment for affective disorders is advised to be administered during the hours after waking up (Dallaspezia *et al.* 2012). Our results suggest that the timing of the exposure to light >1000 lux in elderly with ID might therefore be suboptimal for the regulation of the circadian rhythm, sleep and mood as shown in other populations.

Only about half of elderly with ID met the suggested thresholds that are associated with better sleep efficiency and mood for most of their days. The threshold analyses were merely explorative to qualify the light exposure in our study sample. As the thresholds were based on cross-sectional data from other populations, no conclusion can be drawn about the causal relationship between light exposure and sleep or mood. Nonetheless, we conclude that elderly with ID are exposed to low levels of light >1000 lux, thresholds that might be associated with better sleep efficiency and mood.

Elderly with ID were exposed to more light >1000 lux during the week than during weekend days and the thresholds for light exposure that are associated with better sleep efficiency and mood are met more often during the week (50.6% and 62.3%) than during the weekend (18.5% and 28.9%). As the initiative to undertake activities or to go outside often has to come from others like professional caregivers and less activities are organised during the weekend in the group homes, elderly with ID might be less active during the weekend and exposed to less outdoor light levels then during the week.

Strengths and limitations

This is the first study on personal daily light exposure in elderly with ID. Strengths of the current study are the large study sample, the continuously measured person-bound illuminance and the additional calibration of the light loggers. Also, we composed the most reliable data set with the least missing values.

The amount of zero-values ranged between 34% and 51% over the timeframes. These values might be a result of wearing the light sensor incorrectly. Exploratory tests with the HOBO data loggers showed that wearing the logger the wrong way around or underneath a coat, the data logger would record a 10th of the light exposure when the HOBO was worn correctly. Alternatively, the zero-values might also be true low light levels a little above 0 lux. Since it is unclear what the zero-values resembled, only the data of timeframes with less than 25% missing values were used.

Despite the fact that measuring personal light exposure was shown to be feasible in our population before (Van Duijnhoven *et al.* 2017), the current study has shown that retrieving valid data from these measurements is an additional challenge. As a result of the missing values, data of 200 waking days and complete data of nine participants had to be excluded. This challenge adds to the importance of the current data on light exposure in elderly with ID.

Aside from the missing data on light exposure, data on medical status were missing too. Therefore, performing subset analyses for psychiatric disorders or visual impairments was not possible. Neither could we correct for possible sleep movement disorders, that might have affected the bedtimes and duration of the waking day. In future research, it is strongly advised to collect this data too. Based on results from subset analyses, guidelines for the lit environment could be formulated for specific populations of elderly with ID, for instance behavioural disorders, visual impaired residents or residents with neurodegenerative disorders like dementia.

In future research, underestimating light exposure could be prevented by the use of two light sensors; one on a broche above the clothing worn inside and one on the jacket worn outside (Te Lindert *et al.* 2018; Itzhacki *et al.* 2019). As the circadian rhythm is entrained under the influence of light with shorter wavelengths (Wright and Lack 2001), measuring the spectral properties of light exposure would be advised too (Aarts *et al.* 2017). In addition, to gain insight into the light exposure over the full day and year, measurements should be extended to during the night as well as spring and autumn. Lastly, an intervention study could be performed to study the relationship between light exposure, sleep and mood in elderly with ID in order to study the impact of light exposure in this population.

Conclusion

This is the first study on personal daily light exposure in elderly with ID living in group homes. Elderly with ID spend most of their waking day in low light levels with minor variation over the day. Our results showed that light exposure >1000 lux in elderly with ID was timed in the afternoon. Overall, exposure in elderly with ID did not meet the proposed values associated with better sleep and mood. The low light levels in the living environment as shown by Jelluma *et al.* (2012) are not counterbalanced by the personal daily light exposure of the elderly with ID. Insufficient and inadequately timed light exposure might play a role in the development of sleep and mood disorders that are prevalent in this population. Given the importance of adequate light exposure for regulation of sleep and mood, and the prevalence of sleep and mood problems in elderly with ID, the current study suggests that the lit environment for this already frail population should be given more attention.

Author contributions

All authors made substantial contributions to the design of this study and/or were involved in the interpretation of the data. All authors drafted the work, and reviewed and revised the manuscript critically. All authors approved the final version to be published.

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Conflict of Interest

No conflicts of interest have been declared.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S4. Participant characteristics of the participants with valid timeframes, comparison of participants from study one and study two with valid timeframes on demographics.
Table S5. Light exposure over week and weekend; minutes of illuminance in categories 1-100 lux, 101-500 lux, 501-1000 lux and >1000 lux and missing data during timeframes Waking day, Morning and Evening with <25% missing values of 48 participants.
Table S6. Light exposure over months; minutes of illuminance in categories 1-100 lux, 101-500 lux, 501-1000 lux and >1000 lux and missing data during timeframes Waking day, Morning and Evening with <25% missing values of 48 participants.