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Light up: an intervention study of the effect of environmental dynamic lighting on sleep–wake rhythm, mood and behaviour in older adults with intellectual disabilities

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Abstract

Background Evidence-based interventions to improve the sleep–wake rhythm, mood and behaviour in older adults with intellectual disabilities (ID) are limited. Increasing light exposure has been shown to be effective in improving the sleep–wake rhythm, mood, and behaviour in other populations. The current study investigates the effect of installing environmental dynamic lighting in common living rooms of care facilities on sleep–wake rhythm, mood, and behaviour in older adults with ID.

Methods A non-randomised, non-concurrent, multiple baseline study was performed from October 2017 to May 2018. Fifty-four participants [mean (SD) age of 63.42 (8.6) years, 65% female] in six care facilities were included. All participants had three baseline measurements (Weeks 1, 5 and 9). Dynamic lighting was installed in Week 10, after which three intervention measurements took place (Weeks 12, 17 and 24). Sleep characteristics and the sleep–wake rhythm were assessed using actigraphy (GENEActiv). Mood was measured with the Anxiety, Depression and Mood Scale (ADAMS) and behaviour with the Aberrant Behaviour Checklist (ABC).

Results Mixed-effect regression analysis showed a worsening of the primary outcome interdaily stability ($P = 0.001$). This could be attributed to one care facility, whereas interdaily stability did not change in the other care facilities ($P = 0.74$). Dynamic lighting led to earlier mid-sleep ($P = 0.003$) and sleep onset ($P < .0001$) and improved mood as indicated by lower

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scores on the ADAMS depression (−0.64 SD, $P < 0.001$) and social avoidance (−0.47 SD, $P = 0.004$) subscales. The prevalence of screening above cut-off for depression decreased from 23 to 9.8% (OR = .16, $P = 0.003$). For behaviour, a decrease was seen in hyperactivity (−0.43 SD, $P < 0.001$), lethargy (−0.35 SD, $P = 0.008$) and irritability (−0.33 SD, $P < .001$) as measured with the ABC. No adverse effects were reported.
Conclusion Installing dynamic lighting in common living areas for older adults with ID improved the mood and behaviour of the residents up to 14 weeks after placement. Integrated dynamic lighting is a promising, undemanding and potentially effective addition to improve mood and behaviour in care organisations for people with ID, but does not seem to do so by improving sleep or sleep–wake rhythms.

Keywords chronotherapy, circadian rhythm, depression, elderly, intellectual disabilities, sleep problems

Introduction

With a prevalence of up to 72%, sleep problems are common in older adults with intellectual disabilities [ID, a condition characterised by significant limitations in both intellectual functioning (IQ of lower than 70) and adaptive behaviour that originates before the age of 22 defined by the American Association on Intellectual and Developmental Disabilities (aaidd.org)] who live in residential care facilities (Van De Wouw *et al.* 2013b). Night waking and short sleep are the most common sleep problems, and overall sleep in older adults with ID typically involves lying in bed for 10.5 h, lying awake during the night for about 2 h and a low sleep efficiency of 70% (Van De Wouw *et al.* 2013b). Poor sleep in older adults with ID is associated with depressive symptoms (Van De Wouw *et al.* 2013b) and challenging behaviour during the day (Didden *et al.* 2002; Van De Wouw *et al.* 2012). Despite the high prevalence of sleep problems in persons with ID, few evidence-based interventions are available for improving sleep in this population (Priday *et al.* 2017).

Sleep problems and disrupted sleep in older adults with ID might be related to the fragmented and unstable sleep–wake rhythm (Maaskant *et al.* 2013), as is seen in older adults in the general population (Luik *et al.* 2013). The sleep–wake rhythm follows a circadian rhythm, a rhythm of about 24 h that is apparent in most human physiological processes and behaviour (Minors and Waterhouse 1981). The circadian rhythm is driven by a circadian clock that lies in the suprachiasmatic nucleus in the hypothalamus of the midbrain. Although always present, the rhythms are entrained to the natural light–dark cycle by external cues called *Zeitgebers* (German for 'time-givers') (Golombek and Rosenstein 2010). The most important *Zeitgeber* for the circadian rhythm is (sun)light (Duffy *et al.* 1996). Light enters the eye, which acts on the intrinsically photosensitive retinal ganglion cells (ipRGC), which project to the suprachiasmatic nucleus through the retinohypothalamic tract (Hattar *et al.* 2002). In the general population, insufficient or badly timed light exposure is related to disrupted sleep (Linton *et al.* 2015; Dautovich *et al.* 2019), lower sleep quality (Aarts *et al.* 2018) and mood complaints (Espiritu *et al.* 1994; Driesen *et al.* 2010; Moreno *et al.* 2019; Burns *et al.* 2021).

Enhancing environmental light exposure using ceiling mounted light is shown to be effective in improving the sleep–wake rhythm and sleep in older adults (Sloane *et al.* 2008; Hadi *et al.* 2019) and older adults with dementia (Van Someren *et al.* 1997; Riemersma-Van Der Lek *et al.* 2008; Figueiro *et al.* 2014; Hadi *et al.* 2019). Increasing light exposure with conventional light therapy using a light box has been shown to reduce depressive symptoms in older adults (Sloane *et al.* 2008), though the results on conventional light therapy the sleep–wake rhythm in older adults living in care facilities are inconclusive (Hjetland *et al.* 2020).

In adults with ID, conventional light therapy provided promising results in reducing depressive symptoms below the clinical cut-off point (Hamers *et al.* 2020). However, probably due to limited statistical power, the reduction of depressive symptoms after light therapy was not significantly different from the control group that did not receive light therapy (Hamers *et al.* 2020). Very limited evidence is available for a beneficial effect of light on the sleep–wake rhythm in ID. There is only one case report, which showed that increasing daily natural light exposure was effective in stabilising the sleep–wake rhythm in a 34-year-old man with ID

(Short and Carpenter 1998). No studies are available on the effect of light exposure on sleep and sleep problems in people with ID.

Enhancing environmental light exposure in older adults with ID is particularly of interest as residential care facilities for people with ID are often poorly lit. Only 3.3–6.5% of residential care facilities meet the recommendations in the European lighting guideline (EN 12464-1:2003) (Jelluma *et al.* 2012). The poor light exposure indoors is not counterbalanced by outdoor bright light, as personal daylight exposure in older adults with ID is low and does not meet the recommended light intensity that has been associated with better sleep and mood in the general population (Böhmer *et al.* 2021b). Given these poor lighting conditions and limited exposure to (day)light, improving the lit environment in care facilities for people with ID might be beneficial for sleep and mood, as is previously seen in other populations like older adults living in residential care facilities (Riemersma-Van Der Lek *et al.* 2008; Sloane *et al.* 2008; Hadi *et al.* 2019).

The aim of this study was to investigate the effect of increasing environmental light exposure on sleep–wake rhythm, sleep problems, mood and behaviour in older adults with ID living in residential care facilities. Therefore, we performed a non-randomised, non-concurrent, multiple baseline study in which we installed environmental dynamic lighting in common living rooms in care facilities. We hypothesised that introducing dynamic lighting would stabilise the sleep–wake rhythm and decrease its fragmentation. In addition, the effect of dynamic lighting on other characteristics of the sleep–wake rhythm, sleep problems, mood and behaviour was studied exploratory. We hypothesised that dynamic lighting would also have a positive effect on these outcomes.

Methods

Study setting and participants

In this study, we focus on older adults (>40 years) with intellectual disability (ID) who live in a residential care facility. Intellectual disability is defined as 'a condition characterized by significant limitations in both intellectual functioning (IQ<70) and adaptive behaviour that originates before the age of 22' (definition according to the American Association on Intellectual and Developmental Disabilities).

Participants were recruited from residential care facilities run by Middin, a care organisation for people with disabilities in the Netherlands providing care for 4400 people. Middin's care facilities are located in a central setting or are community based and provide specialised care based on support needs rather than age. Residents are assisted by professional caregivers with merely all daily activities like dressing, eating and going to bed. Residents take part in in-home activities that are provided during the day or go to day-care facilities or other residences. Medical and psychological care is provided by professional caregivers, physicians specialised in ID medicine and behavioural therapists. Each resident is assigned a tutor and a professional caregiver that knows the resident for a longer time and well that is concerned with serving the interests of the resident within the care facility.

People with ID aged 50 and over are as frail as older people without ID aged 70 and above (Schoufour *et al.* 2013). In addition, we wanted to include as much as residents from the selected care facilities as possible to take part in this study. Therefore, we choose 40 as the minimum age for our sample.

In 2016, Middin had 83 residential care facilities with residents aged ≥40 years. Twenty-nine homes had at least 10 residents with ID aged 40 or older (total residents aged ≥40 years = 552). From these 29, the six care facilities with (1) the most residents over 40 years of age and (2) where residents eat their meals together in a common living room where the dynamic lighting could be placed were selected to participate in this study. Because of financial reasons, dynamic light installations could be placed in six group homes. Therefore, group homes with the most residents eligible to participate were selected for this study to be able to meet the required number of participants for this study. The six participating care facilities were all community-based.

The Medical Ethical Committee of Erasmus MC University Medical Center Rotterdam, the Netherlands, gave an exemption for a comprehensive application for this study (MEC-2017-467). Residents who could decide on participation themselves received an easy-to-read information letter about the study before signing the informed consent form. For

the other residents, the legal representatives signed the informed consent form.

Inclusion criteria

The six participating care facilities had 121 residents in total. Residents were eligible for participation if they (1) were aged 40 or older; (2) had mild, moderate, severe or profound ID (i.e. IQ below 70); and (3) spend at least 1 h a day in the living room, of which 30 min between 7:00 a.m. and noon in order to guarantee exposure to the intervention. Residents known to be seriously ill were excluded from participation. The eligibility for participation of all residents of the participating care facilities was determined in consultation with the behavioural therapist, tutors and personal caregivers concerned with the care facility.

Dynamic lighting installation

The ceiling-mounted dynamic lighting installation (YSELED, Light Technology, the Netherlands) delivered a maximum of 12 000 lumen (120 W) up and 6000 lumen (54 W) down. Per care facility, a professional light plan was designed for the complete living room. As all living rooms differed in size, shape, architecture and access to outdoor light, we aimed to standardise the environmental lighting by programming the installations to deliver an illuminance of 1000 lux and 4500 K at eye level in gaze direction (120 cm from the floor) between 7:00 a.m. and 6:00 p.m. and to dim down to 150 lux and 2700 K at eye level automatically at 6:00 p.m.

The illuminances during daytime were previously shown to entrain circadian rhythms in healthy people in temporal isolation (Middleton *et al.* 2002) and are comparable with previous studies on ceiling-mounted light installations (Van Someren *et al.* 1997; Riemersma-Van Der Lek *et al.* 2008). Illuminances during the night time were determined based on the lower limits of the installation; the illuminances and colour temperature were minimised to limit the activating effects of light. Figure 1 shows the lighting installation in the living rooms of two of the participating care facilities.

Light exposure in the living room was measured 1 day during the last week of baseline and 1 day during the first week of the intervention. A full description of the procedure and the average light exposure during baseline and after installing dynamic lighting is shown in Fig. 2. Mean light exposure between 7:00 a.m. and 6:00 p.m. was 68 lux (SD = 46 lux) at baseline and 989 lux (SD = 211 lux) during intervention. Light exposure at 07:00 p.m. was 23 lux (SD = 8 lux) during baseline and 85 lux (SD = 34 lux) during intervention.

Study design

A schematic overview of the study design is presented in Fig. 3. This study used a non-randomised, non-concurrent, multiple baseline design. The multiple baseline design reveals the intervention effect by ruling out the risk of unforeseen events (history effect) by including multiple baseline measurements and introducing the intervention at different points in time (Kazdin and Kopel 1975).

Figure 1. Dynamic lighting in the common living rooms of two participating care facilities for older adults with intellectual disabilities. [Colour figure can be viewed at wileyonlinelibrary.com]

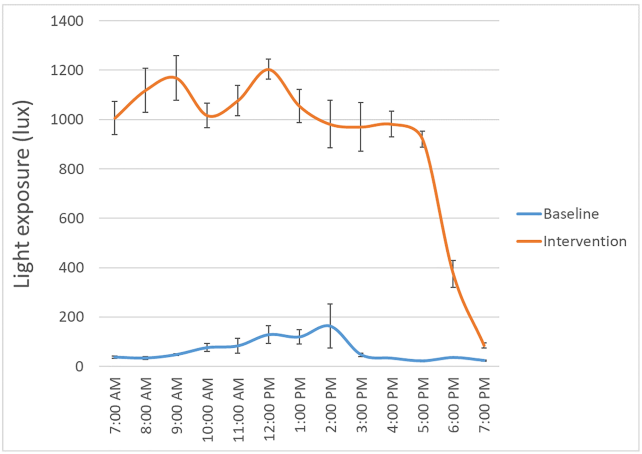

Figure 2. Average light exposure of participants (n = 52) while in the common living room between 7 a.m. and 7 p.m. during baseline and intervention. Notes: Light exposure was measured 1 day during the last baseline measurement week and 1 day during the first intervention measurement week. Light exposure was measured in the direction of gaze using a Testo 545 digital lux meter (Testo SE & Co. KGaA, Germany), so the data represent the light levels that enter the eye. Light exposure measurements took place hourly between 7 a.m. and 7 p.m. whenever participants were in the common living area. If a participant was not in the common living area at the moment of the measurement, the measurement for that time point and that participant was missing. Despite the inclusion criterion of spending at least 1 h a day in the common living room, two participants missed all light exposure measurements. One measurement of 179 lux at 2 p.m. during the intervention measurement was considered an outlier and was not included in the analyses. The graph depicts 777 light exposure measurements from 52 participants in six facilities. During baseline, light exposure was measured on average 6.76 times per participant. Mean light exposure between 7:00 a.m. and 6:00 p.m. was 68 lux (SD = 46 lux) at baseline and 989 lux (SD = 211 lux) during intervention. Light exposure at 07:00 p.m. was 23 lux (SD = 8 lux) during baseline and 85 lux (SD = 34 lux) during intervention. [Colour figure can be viewed at wileyonlinelibrary.com]

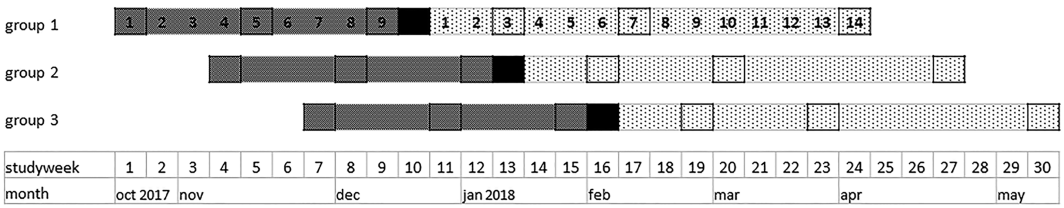

Figure 3. Study design; non-randomised, non-concurrent, multiple baseline design on dynamic lighting on sleep–wake rhythm, mood and behaviour. Notes: The baseline period of 9 weeks is indicated by the dark grey rectangles. Black squares indicate the week that the dynamic lighting was installed. The intervention period of 14 weeks is indicated by dotted rectangles. Weeks of measurements are indicated with black borders.

Care facilities were non-randomly paired to create three pairs with a similar number of participants. Each pair started 4 weeks after the previous one and followed the same study procedure. During baseline, three measurement periods of 1 week took place in Weeks 1, 5 and 9. After placement of the dynamic lighting in Week 10, measurements during the intervention period took place in Weeks 12, 17 and 24.

In order to study the effect of the dynamic lighting, the study was conducted when the natural photoperiod was shortest and was centred on the winter solstice. The study started on 18 October 2017 and ended on 24 May 2018. The total study period was 30 weeks.

Materials

Sleep–wake rhythm and sleep were measured using the GENEActiv (Activinsights, Kimbolton, UK; 100 Hz), a wrist-worn piezoelectric accelerometer. The GENEActiv was worn continuously during each measurement week, for 7 consecutive days and nights. The GENEActiv is comparable (Te Lindert and Van

Someren 2013) with the Actiwatch 2 (Cambridge, UK), which is valid and reliable in older adults with ID (Van De Wouw *et al.* 2013a).

For sleep–wake rhythm analysis, all 24-h periods with more than 4 h of missing data were excluded. Measurements per measurement week were considered valid if they included a total of at least 96 h of valid data. The sleep–wake rhythm analysis provided one value per measurement week, so a maximum of six values per participant over the complete study period. Sleep–wake rhythm parameters were calculated using non-parametric circadian rhythm analyses (Van Someren *et al.* 1999). The primary outcomes of the analyses were interdaily stability (IS) and intradaily variability (IV). IS represents the stability of the sleep–wake rhythm; IV indicates the fragmentation of the rhythm.

Sleep characteristics were calculated using the Actant—Activity Analysis Toolbox (Te Lindert and Van Someren 2013). All 24-h periods with more than 4 h of missing data were excluded, and measurements were considered valid if they included at least one night of valid data. The analysis of sleep characteristics provided one value per night, so a maximum of seven per measurement week and maximum of 42 values per participant over the complete study period. The sleep characteristics of interest were total sleep time (TST; total time asleep between sleep onset and final wake time), waking after sleep onset (WASO; time awake between sleep onset and final wake time), sleep efficiency (percentage of sleep between sleep onset and final wake time), sleep onset time, final wake time, number of wake bouts, wake bout duration, number of sleep bouts and sleep bout duration. Mid-sleep, the midpoint between sleep onset and final wake time, was calculated and used explorative as a proxy for circadian phase (Kantermann and Burgess 2017). Short sleep duration was defined as a TST <6 h (Van Den Berg *et al.* 2009; Magee *et al.* 2011; Van De Wouw *et al.* 2013b), and night waking was defined as WASO >90 min (Ensrud *et al.* 2009; Ensrud *et al.* 2012).

Mood and behaviour

The Dutch translation of the Anxiety, Depression and Mood Scale (ADAMS) was used to measure mood. The ADAMS is a proxy screening scale for the presence of symptoms of depression and anxiety in adults with ID. It consists of 28 items scored on a 4-point scale (0–3) covering four subscales: Depression, Anxiety, Social Avoidance and Other Symptoms. A cut-off score of ≥14 points (Screening Depression) was used for the presence of depressive symptoms and a cut-off score of ≥10 (Screening Anxiety) for anxiety symptoms. The test–retest reliability of the ADAMS for adults with ID is good to excellent (Hermans *et al.* 2018).

Behaviour was measured using the Aberrant Behaviour Checklist (ABC) (Aman *et al.* 1985), consisting of 58 items that are scored on a scale ranging from 0 (*no problem*) to 3 (*very problematic*). The ABC consists of the subscales Hyperactivity, Irritability, Lethargy, Stereotypy and Inadequate Speech (Rojahn *et al.* 2011). The internal consistency of the ABC in adults with ID is excellent (Rojahn *et al.* 2011).

For each participant, questionnaires were filled out once per measurement week by the tutor. In case the tutor was not available, the questionnaires were filled out by the assigned caregiver who knew the participant well. This person was identified by the other caregivers of the group home based on the time and/or intensity of the contact with the participant.

Adverse effects

To account for possible unwanted side effects of the dynamic lighting, adverse effects (e.g. eye complaints, headache and dizziness) in participants were rated on a 4-point scale (0 = *absent*, 1 = *probably absent*, 2 = *probably present*, 3 = *present*) by the tutor or the professional caregivers once every measurement week (Riemersma-Van Der Lek *et al.* 2008).

Demographics, medical status and medication use

At baseline, information on age and sex was obtained from the medical records. Level of ID was obtained from behavioural therapists' records and classified as mild (IQ 55–70), moderate (IQ 35–55), severe (IQ 25–35) or profound (IQ <25).

The tutor or professional caregiver filled out questionnaires on the activities of daily living (ADL) and mobility of the participant. Basic ADL (e.g. feeding, dressing and toilet use) was assessed with the Barthel Index (Mahoney and Barthel 1965). Instrumental ADL (e.g. telephone use, food preparation and finances) was assessed with the

Lawton index (Lawton and Brody 1969). A checklist on medical status, genetic syndromes and medication use was filled out based on the medical records by either the responsible physician or the researcher. Professional caregivers provided information about alcohol use (yes/no), smoking (yes/no), mobility (independent/with support/wheelchair) and whether the participant took part in organised daily activities and. Basic ADL, instrumental ADL, mobility, medical status and medication use were collected at the first baseline measurement and last intervention measurement.

Sample size calculation

Interdaily stability is shown to be sensitive to changes in light exposure (Van Someren *et al.* 1997). The sample size calculation indicated that 20 participants with six repeated observations ($r = 0.5$) were needed to detect a change of 0.5 SD in IS after installing the light installations, with a small effect size ($r = 0.3$) and a power of 0.80. Considering the limited effort of participation needed from the residents, we aimed to include as many participants as possible within the participating care facilities.

Statistical analyses

Multilevel regression analysis was used to correct for the correlation between measurements within the same participant, accounting for the one-level nested structure of the data. Analyses of continuous outcomes were performed using RStudio (RStudio Team 2020) with the nlme package; dichotomous outcomes were analysed using the geeglm package with the 'exchangeable' covariance matrix.

Given the multiple baseline design, all analyses included the variables 'intervention' (dynamic light present, yes/no) and 'time'. Time represented study week (range 1–30) for all outcome variables except for the sleep estimates, where time indicated the date of the measurement. Demographics, medical status and medication use at baseline that correlated significantly ($P < 0.05$) with the outcome variables at baseline or during the intervention and were present in at least 10 participants were included in the analyses as covariates. Missing values were well under 5% for all covariates (instrumental ADL: 1.9%; medical status: 1.9%; medication use; 3.7%); therefore, no strategy to replace the missing values was applied. As TST and WASO are highly correlated, analyses for the WASO were corrected for assumed sleep (minutes between sleep onset and final wake time).

The effect of dynamic light was only analysed for outcome variables that met the assumption for multilevel regression analysis and outcome variables that were stable during baseline, as this is the assumption for analysis of a study following the multiple baseline design. For each outcome variable, a model is fitted based on all individual data points from the participants, and the aim was to find the model that fits the data best. Analysis started with an elaborate model, including variables time and intervention, an interaction term time * intervention and non-linear effects (natural spline, df = 2) for time and age. A random intercept for participant was included. Models were simplified using ANOVAs to test the added value of splines and interaction terms. As we were interested in the added effect of the variable intervention, covariates were kept in the model irrespective of their significance. To interpret the added effect of the dynamic light on the outcomes, the results of the variable 'intervention' over the complete intervention period are described. Final models and full test results of these models with a natural spline are reported in Appendix A.

To check whether the dynamic lighting had a different effect in participants who scored above the cut-off for depressive symptoms at least once during baseline, additional analyses was performed including an interaction term ADAMS Screening Depression * intervention.

To adjust for multiple testing, the threshold *P* value was reduced to 0.011 for sleep–wake rhythm and sleep estimates (Sidak correction, $r = 0.5$, alpha = 0.05 with 20 outcome measurements), and the *P* value for mood and behaviour was reduced to 0.019 (Sidak correction, $r = 0.6$, alpha = 0.05 with 11 outcome measurements).

An exploratory test of the possible adverse effects of the intervention was performed with the simplest model with fixed effects for time and intervention, random effects for participants and no covariates. Last, the effect of dynamic light on ADL, IADL, mobility, medical status and medication use from baseline to last measurement were checked exploratory.

Results

Participant characteristics

Figure 4 shows the flow chart for the inclusion of participants and collection and selection of data. A total of 86 residents were eligible to participate, 54 of whom gave informed consent. Twenty-nine participants could sign informed consent themselves; for the remaining 25 participants, the legal representative signed. Three participants only started at the third measurement, as signed informed consent was not received earlier. One participant moved to another care facility after the third baseline measurements and therefore dropped out of the study. The baseline data of this participant was used in analyses.

Participants with data from both actigraphy and questionnaires did not differ significantly from participants with only data from questionnaires on demographics, medical status, medication use and questionnaire outcomes for the first baseline measurements (Table 1).

Sleep–wake rhythm and sleep

For the sleep–wake rhythm, 39 participants provided valid actigraphy data for at least 96 h. The amount of valid data did not differ between care facilities ($P = 0.113$). The length of the analysed period was on average 6.1 nights (SD = 0.95). A total of 1041 nights of valid data from 42 participants were available for analysis of sleep estimates (average of 4.1 nights per participant per measurement) (Table 2).

After installing the lights, IS of the sleep–wake rhythm fell by 0.008 for every week during the intervention ($P = 0.001$; Fig. 4a). Further inspection showed that this could be attributed to the participants ($n = 9$) of one specific home (data available from authors). As this home did not differ from the other five homes in the baseline characteristics or baseline scores, it was not justified to exclude this home from the analyses. However, explorative analyses excluding this home showed that IS of the sleep–wake rhythm was not affected by the lighting in the remaining five homes ($P = 0.74$).

Dynamic lighting had no significant effect on IV (Fig. 5b), L5, L5 onset, M10, M10 onset, amplitude and RA of the sleep–wake rhythm (Table 3).

Even though we did not select our participants based on the presence of sleep problems, at baseline, 57.1% of our study sample had at least one sleep problem. With regard to the effect of dynamic light on sleep outcomes, the sleep onset was significantly earlier ($P < 0.0001$; Fig. 5c), as was mid-sleep

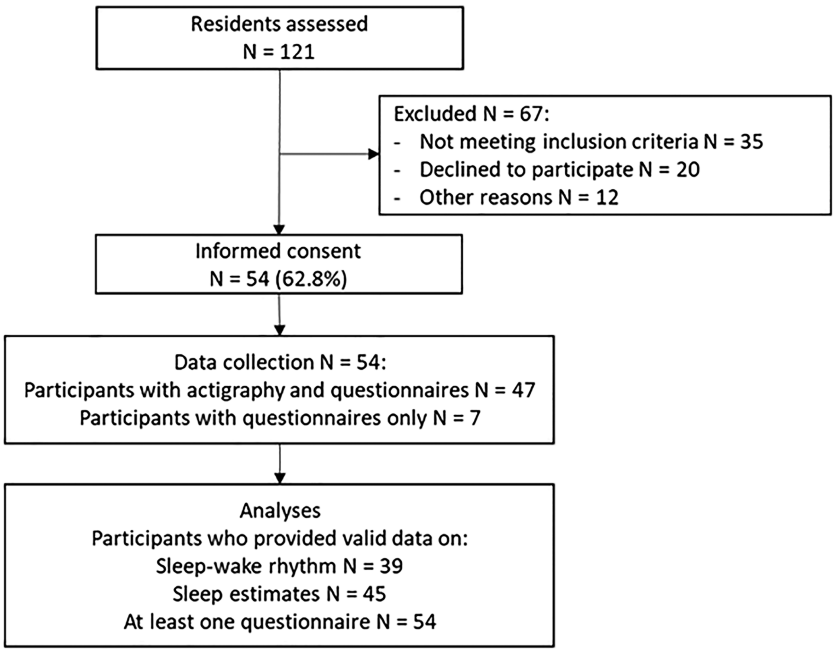

Figure 4. Flow chart of selection of care facilities, inclusion of participants and selection of valid data.

Table 1 Demographics, daily functioning, medical status and medication use of 54 participants at first baseline measurement

Measurements[a]			
Participants, count		54	
Age, mean (SD, range)		63.4	(8.6, 46–79)
Female, count		35	64.8%
Level of ID, count	Mild	12	22.2%
	Moderate	30	55.6%
	Severe	1	1.9%
	Unknown[b]	11	20.4%
Genetic syndromes associated with ID	Down syndrome	10	18.5%
	Fragile X	1	1.9%
	No/unknown/syndrome not specified	43	79.6%
Activities of daily living, range 0–20, mean (SD)		14.9	(5.8)
Instrumental activities of daily living, range 8–33, mean (SD)		11.0	(2.8)
Mobility, count	Independent	39	72.2%
	Support	8	14.8%
	Wheelchair	7	13.0%
Medication use, count	Antidepressants	9	16.7%
	Antipsychotics	16	29.6%
	Sleep medication	3	5.6%
	Benzodiazepines	18	34.6%
	Anti-epileptic	8	14.8%
	Beta-blockers	10	18.5%
	Other psychotropic medication	6	11.5%
	At least one of the above	36	66.7%
	Missing medication use, *n*	2	3.7%
Co-morbidities, count	Depression	5	9.4%
	Anxiety	6	11.3%
	Sleep problems	5	9.4%
	Dementia	6	11.3%
	ADHD	3	5.7%
	Autism	1	1.9%
	Cardiovascular disease[c]	22	41.5%
	Epilepsy	11	20.8%
	Spasticity	3	5.7%
	Visual impairment	9	17.0%
	Hearing impairment	18	33.9%
	Missing co-morbidities, *n*	1	1.9%

[a]Range is shown worst to best.
[b]Data on level of ID were retrieved from the behavioural or medical records, but are not always recorded.
[c]Umbrella variable of all reported cardiovascular conditions, for example, hypertension, pacemaker or cardiac arrhythmias.

($P = 0.0003$; Fig. 5d). Wake bout duration increased ($P = 0.008$; Fig. 5e). These results could not be attributed to a specific care facility. There was no effect of lighting on WASO, sleep efficiency, final wake time, number of wake bouts, number of sleep bouts or sleep bout duration. The lighting did not affect the occurrence of night waking and short sleep.

Mood and behaviour

Of the six questionnaires that were sent out for each participant, on average 5.09 questionnaires were filled out, with 92% of the questionnaires for a given participant being filled out by the same assigned professional caregiver (Table 4).

For mood, the scores on the ADAMS depression scale decreased by 3.42 points (CI: −4.92, −1.92, $P < 0.0001$; Fig. 5f) after installing the dynamic lighting installation, a reduction of 37% (0.61 SD). During the baseline period, on average 23% of participants scored above cut-off for depressive symptoms. After installing dynamic lighting, this decreased to an average of 9.8% (OR = .16, $P = 0.003$). There was a strong but non-significant interaction between the intervention and having depressive symptoms at baseline ($P = 0.06$). ADAMS depression scores of the 21 participants who were classified as having depressive symptoms at least once during baseline decreased by 5.07 points [CI: −7.82, −2.31, − 39% (.97 SD), $P < 0.001$], whereas depression scores of the other 31 participants decreased by 2.25 points [CI: −3.97; −.53, − 34% (.71 SD), $P = 0.012$]. No lighting effect was found for anxiety symptoms or the prevalence of above cut-off scores for the Anxiety subscale (Table 5).

With regard to behaviour, after installing dynamic lighting, the scores significantly improved on the social avoidance subscale of the ADAMS (34% or 0.41 SD, $P = 0.004$) and the subscales hyperactivity (relative 51% or 0.57 SD, $P = 0.0001$), lethargy (34% or 0.37 SD, $P = 0.008$) and irritability ($P = 0.0002$) of the ABC. Lighting did not affect scores on ABC inadequate speech (Fig. 5g).

Adverse effects and other outcomes

There was no indication of adverse effects after introducing the dynamic lighting. There was a significant decrease in eye complaints ($b = -0.35$, $P = 0.03$), hyperactivity ($b = -0.31$, $P = 0.01$) and nervousness ($b = -0.30$, $P = 0.03$), which were not considered adverse effects. Dynamic lighting did not

Table 2 Sleep–wake rhythm and sleep estimates up to 14 weeks after installing dynamic lighting

	Assessment scale[a]		Baseline, mean (SD)			Intervention, mean (SD)		
			1	2	3	4 (3rd week after installation)	5 (7th week after installation)	6 (14th week after installation)
Sleep–wake rhythm	IS	Range, 0–1	(*n* = 23)	(*n* = 31)	(*n* = 27)	(*n* = 25)	(*n* = 26)	(*n* = 25)
	IV	Range, 2–0	0.69 (0.13)	0.65 (0.16)	0.7 (0.17)	0.68 (0.18)	0.64 (0.17)	0.64 (0.19)
	L5	Range, 0–60	0.61 (0.26)	0.55 (0.24)	0.63 (0.31)	0.65 (0.33)	0.68 (0.35)	0.57 (0.24)
	L5-onset	hh:mm	10.16 (6.15)	9.17 (5.08)	10.43 (5.38)	11.08 (6.94)	11.02 (6)	10.45 (5.59)
	M10	Range, 0–60	00:17 (1:43)	00:45 (2:01)	00:59 (1:42)	00:28 (1:43)	00:17 (1:28)	00:29 (1:32)
	M10-onset	hh:mm	47.7 (9.47)	47.23 (8.77)	47.83 (9.95)	47.23 (10.06)	46.12 (10.01)	47.94 (8.12)
	Amplitude	Range, 0–60	9:32 (1:36)	10:11 (2:01)	10:07 (2:37)	10:14 (2:04)	9:43 (2:04)	10:29 (2:19)
	RA	Range, 0–1	37.53 (9.78)	38.06 (8.93)	37.39 (10.47)	36.15 (10.85)	35.09 (10.28)	37.49 (10)
			0.66 (0.15)	0.68 (0.14)	0.64 (0.15)	0.63 (0.16)	0.62 (0.15)	0.64 (0.17)
Sleep estimates	Total sleep time (TST)	Hours	(*n* = 35)	(*n* = 35)	(*n* = 29)	(*n* = 30)	(*n* = 28)	(*n* = 27)
	Waking after sleep onset (WASO)	Minutes	7.87 (2.29)	7.87 (2.11)	7.56 (2.11)	7.74 (2.24)	7.76 (1.95)	7.45 (2.04)
			87.59 (66.05)	82.59 (59.49)	83.62 (63.4)	96.23 (75.35)	96.77 (66.66)	97.09 (70.57)
	Sleep efficiency	%	84.23 (10.38)	85.34 (8.97)	84.63 (10.01)	82.77 (12.53)	82.79 (10.86)	82.21 (11.64)
	Sleep onset time	hh:mm	22:23 (1:30)	22:36 (1:43)	22:50 (1:41)	22:19 (1:25)	22:20 (1:27)	22:46 (1:40)
	Final wake time	hh:mm	7:38 (1:44)	7:51 (1:42)	7:47 (1:39)	7:40 (1:35)	7:42 (1:27)	7:51 (1:31)
	Mid-sleep	hh:mm	03:00 (1:06)	03:14 (1:15)	03:19 (1:13)	02:59 (1:03)	03:01 (1:04)	03:19 (1:11)
	Number of wake bouts		52.63 (29.8)	52.42 (31.62)	50.17 (30.32)	54.34 (34.79)	55.47 (27.71)	54.31 (33.53)
	Wake bout duration	Minutes	1.78 (1.21)	1.67 (0.87)	1.8 (1.22)	2.16 (2.64)	1.9 (1.36)	2.05 (1.71)
	Number of sleep bouts		52.31 (29.96)	52.21 (31.83)	49.94 (30.46)	54.04 (35.01)	55.22 (27.82)	53.95 (33.62)
	Sleep bout duration	Minutes	12.91 (16.22)	12.76 (10.03)	12.86 (9.30)	13.46 (18.85)	10.57 (5.62)	17.14 (57.92)
	Short sleep (TST <6 h)	%	17.60	15.20	24.90	22.10	16.60	23.70
	Night waking (WASO >90 min)	%	39.00	31.50	34.90	40.10	43.60	43.80

Abbreviations: IS, interdaily stability; IV, intradaily variability; L5, mean activity during least active 5 h; M10, mean activity during most active 10 h; N, number of participants; RA, relative amplitude; SD, standard deviation; TST, total sleep time; WASO, waking after sleep onset.

[a]Range is shown worst to best.

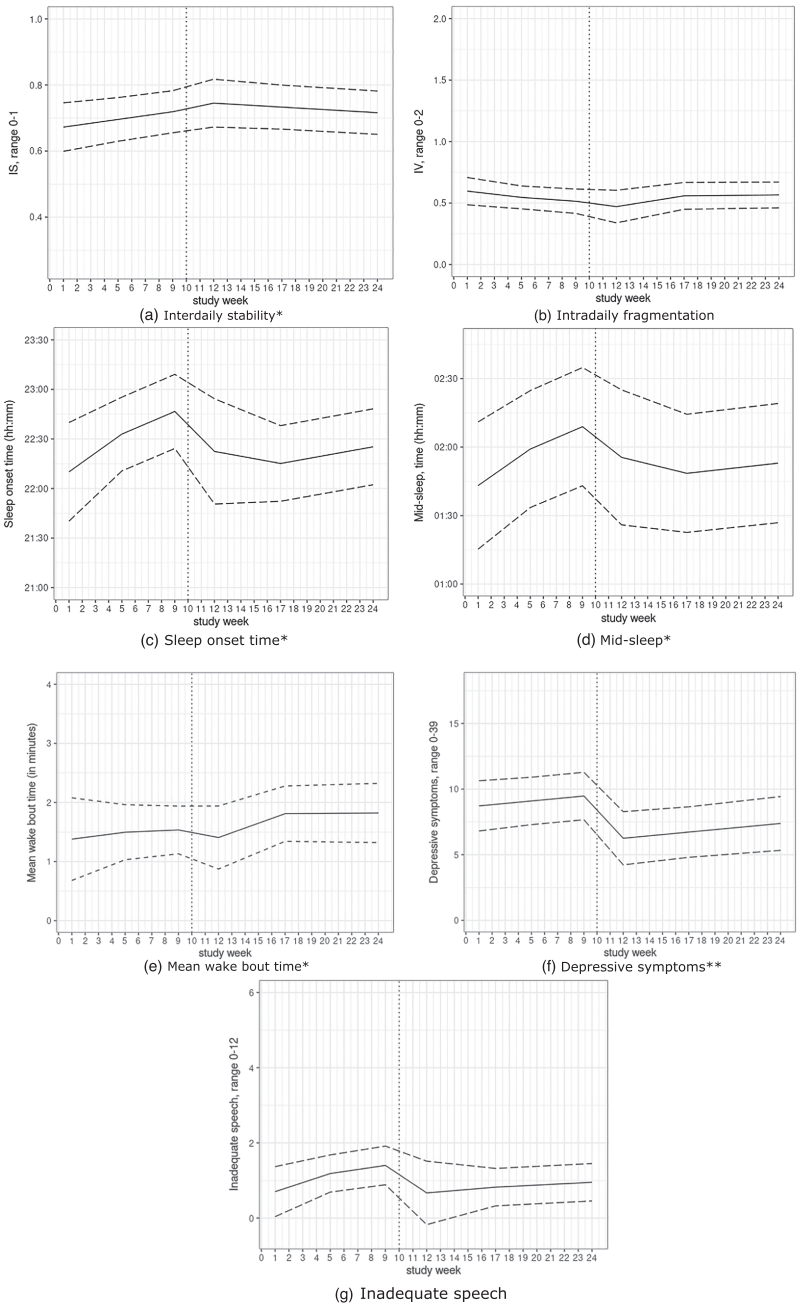

Figure 5. Development over time of sleep–wake rhythm, sleep, mood and behaviour in people with ID showing the effect of dynamic lighting. (a) Interdaily stability*. (b) Intradaily fragmentation. (c) Sleep onset time*. (d) Mid-sleep*. (e) Mean wake bout time*. (f) Depressive symptoms**. (g) Inadequate speech. *$P < .011$. **$P < .0195$. *Notes:* Effect plots for effect of dynamic lighting for primary outcomes (IS and IV), depressive symptoms and outcomes with natural spline (df = 2) for time in model. Dynamic lighting was installed in Study Week 10 (vertical dotted line). Study Weeks 1–9 indicate baseline period, and 11–24 indicate the intervention period. The solid line indicates the estimated development in the scores; the dashed lines indicate the bounds of the 95% confidence interval. After installing the lighting, IS of the sleep–wake rhythm fell by 0.08 points per week during the intervention ($P = 0.001$) and IV ($P = 0.04$) of the sleep–wake rhythm did not change significantly (threshold P value 0.011). Dynamic lighting made sleep onset time ($P = <0.0001$) and mid-sleep ($P = 0.0003$) earlier and increased the mean wake bout time ($P = 0.0076$) (threshold P value 0.011). Dynamic lighting reduced depressive symptom scores by 3.42 points (CI: −4.92, −1.92, $P = 0<.0001$) (threshold P value 0.0195). Inadequate speech did not change with the introduction of dynamic light ($P = 0.0242$) (threshold P value 0.0195).

Table 3 Estimates of effect of dynamic lighting on sleep–wake rhythm and sleep estimates

					Linear mixed model analysis Effect of dynamic light				
	Assessment scale[a]		Valid obs	*n*	Beta	5%	95%	*P* value[b]	Effect size
Circadian rhythm	IS	Range, 0–1	158	38	-[c]	-	-	0.01*	-
	IV	Range, 2–0	158	38	-[c]	-	-	0.04	-
	L5	Range, 0–60	158	38	0.50	−1.15	2.15	0.56	0.09
	L5 onset	Minutes	158	38	−44.00	−87.51	−0.48	0.05	−0.32
	M10	Range, 0–60	158	38	−0.67	−2.38	1.03	0.45	−0.12
	M10 onset	Minutes	149	36	−7.41	−58.36	43.53	0.78	−0.05
	Amplitude	Range, 0–60	158	38	−1.15	−3.46	1.16	0.34	−0.16
	RA	Range, 0–1	158	38	0.00	−0.05	0.04	0.84	−0.03
Sleep estimates	TST	Minutes	966	39	17.39	−5.13	39.91	0.13	0.24
	WASO	Minutes	1027	41	6.38	−2.76	15.52	0.17	0.21
	Sleep efficiency	%	1027	41	−1.55	−3.21	0.11	0.07	−0.28
	Sleep onset time	Minutes	966	39	-[c]	-	-	<0.0001*	-
	Final wake time	Minutes	966	39	−6.47	−25.11	12.18	0.50	−0.11
	Mid-sleep	Minutes	966	39	-[c]	-	-	<0.001*	-
	Number of wake bouts		1027	41	0.96	−3.64	5.56	0.68	0.06
	Wake bout duration	Minutes	1027	41	-[c]	-	-	0.01*	-
	Number of sleep bouts		966	39	0.90	−3.76	5.55	0.71	0.06
	Sleep bout duration	Minutes	966	39	1.95	−3.64	7.53	0.50	0.11
					Log odds ratio	Odds ratio	Wald	Pr (>W)[d]	
	Short sleep (TST<6 h)	%	966	39	−0.42	0.66	2.48	0.115	
	Night waking (WASO >90 min)	%	1027	41	0.15	1.16	0.47	0.4921	

*$P < 0.011$.

IS, interdaily stability; IV, intradaily variability; L5, mean activity during least active 5 h; M10, mean activity during most active 10 h; N, number of participants; RA, relative amplitude; SD, standard deviation; TST, total sleep time; Valid obs, valid observations; WASO, waking after sleep onset.

The relative amplitude (RA) was calculated as the difference between activity during the 10 most active hours (M10) and the 5 least active hours (L5) using the formula RA = M10 − L5/M10 + L5. L5 onset and M10 onset are indicators of the onset of the rest and activity periods.

[a]Range is shown worst to best.

[b]Linear mixed model analysis (lme) adjusted for time, intervention and covariates (full models in Appendix 1), test results presented for the variable intervention (dynamic light); as baseline measurements were not stable, the effect of dynamic lighting on outcome was not performed.

[c]Final model included either interaction term time * intervention and/or natural spline (df = 2) for time; beta values are not representative of effect over complete intervention period. For representation of effect of dynamic lighting for this outcome, see Fig. 5.

[d]Linear mixed model analysis (geeglm) adjusted for time, intervention and covariates (full models in Appendix 1), test results presented for the variable intervention (dynamic light).

affect the scores for ADL, IADL, mobility, medical status or medication use between the first and last measurement (data not shown) (Appendix 2).

Discussion

The current study provides the largest high-quality study to date on an intervention with environmental dynamic lighting for sleep–wake rhythm and mood in older adults with ID living in care facilities. Even though we did not select our participants based on the presence of sleep problems, at baseline, the sleep–wake rhythm was found to be as unstable as that of a large sample of older adults with ID (Böhmer *et al.* 2020), and 57.1% of our study sample had at least one sleep problem. Improving the lit environment in common living rooms resulted in a worsening of the stability of the sleep–wake rhythm.

Table 4 Mood and behaviour outcomes up to 14 weeks after installing dynamic lighting

	Assessment scale[a]		Baseline, mean (SD)			Intervention, mean (SD)		
			1	2	3	4 (3rd week after installation)	5 (7th week after installation)	6 (14th week after installation)
ADESS	Depressive symptoms	Range, 0–39	(*n* = 49) 9.31 (5.23)	(*n* = 48) 10.40 (5.49)	(*n* = 46) 8.54 (5.82)	(*n* = 50) 6.08 (4.72)	(n = 49) 7.04 (6.51)	(*n* = 52) 7.50 (6.69)
	Anxiety symptoms	Range, 0–21	5.71 (3.77)	6.02 (3.08)	5.17 (3.91)	4.12 (3.14)	4.76 (4.02)	4.67 (3.22)
	Social avoidance	Range, 0–21	4.12 (2.93)	4.75 (3.31)	3.57 (3.39)	2.78 (2.91)	3.31 (3.96)	3.37 (3.71)
	Other symptoms	Range, 0–33	7.96 (5.17)	7.88 (5.51)	6.37 (5.78)	4.7 (4.68)	5.33 (5.76)	5.88 (5.98)
	Above cut-off 14: depressive symptoms, %		22.40	29.20	17.40	8.00	6.10	15.40
	Above cut-off 10: anxiety symptoms, %		20.40	20.80	8.70	6.00	10.20	5.80
ABC	Hyperactivity	Range, 0–48	(*n* = 49) 4.57 (5.35)	(*n* = 48) 5.94 (6.13)	(*n* = 46) 4.87 (5.83)	(*n* = 50) 3.33 (4.05)	(n = 49) 4.71 (6.02)	(*n* = 52) 5.06 (6.29)
	Irritability	Range, 0–45	5.27 (5.67)	5.94 (6.03)	5.43 (5.38)	3.90 (4.58)	4.12 (4.77)	4.5 (4.73)
	Lethargy	Range, 0–48	6.10 (5.67)	6.54 (5.39)	5.43 (6.45)	4.02 (4.58)	4.90 (6.91)	5.04 (6.05)
	Inadequate speech	Range, 0–12	1.29 (1.68)	1.54 (1.88)	1.04 (1.79)	0.78 (1.36)	1.14 (1.85)	0.98 (1.35)
	Stereotypy	Range, 0–21	0.67 (1.11)	1.38 (2.41)	1.17 (2.49)	0.71 (1.59)	0.82 (1.89)	0.88 (1.80)

ABC, Aberrant Behaviour Scale; ADAMS, Anxiety, Depression and Mood scale; N, participants; SD, standard deviation.
[a]Range is shown best to worst.

Table 5 Estimates of effect of dynamic lighting on mood and behaviour

			Linear mixed model analysis Effect of dynamic lighting						
	Assessment scale[a]		Valid obs	*N*	Beta	5%	95%	*P* value[b]	Effect size
ADESS	Depressive symptoms	Range, 0–39	285	52	−3.42	−4.92	−1.92	<0.001*	−0.61
	Anxiety symptoms	Range, 0–21	285	52	−1.08	−2.00	−0.15	0.02	−0.32
	Social avoidance	Range, 0–21	285	52	−1.39	−2.30	−0.48	<0.01*	−0.41
	Other symptoms[c]	Range, 0–33	-	-	-	-	-	-	-
					Log odds	Odds ratio	Wald	Pr (>W)[d]	
	Above cut-off 14: depressive symptoms, %		285	52	−1.85	0.16	9.13	<0.01*	
	Above cut-off 10: anxiety symptoms, %		285	52	−0.10	0.90	0.04	0.85	
			Valid obs	N	Beta	5%	95%	*P* value[b]	
ABC	Hyperactivity	Range, 0–48	285	52	−2.32	−3.41	−1.22	<0.001*	−0.57
	Irritability	Range, 0–45	285	52	−1.85	−2.81	−0.89	<0.01*	−0.52
	Lethargy	Range, 0–48	285	52	−2.06	−3.56	−0.55	<0.01*	−0.37
	Inadequate speech	Range, 0–12	285	52	-[e]	-	-	0.02	-
	Stereotypy[c]	Range, 0–21	-	-	-	-	-	-	-

*$P < 0.0195$.

ABC, Aberrant Behaviour Scale; ADAMS, Anxiety, Depression and Mood Scale; N, participants; Valid obs, Valid observations.

[a]Range is shown best to worst.

[b]Linear mixed model analysis (lme) adjusted for time, intervention and covariates (full models in Appendix 1), test results presented for intervention (dynamic lighting).

[c]As baseline measurements were not stable, the effect of dynamic light on outcome was not analysed.

[d]Linear mixed model analysis (geeglm) adjusted for time, intervention and covariates (full models in Appendix 1), test results presented for intervention (dynamic lighting).

[e]Final model included a natural spline (df = 2) for time; beta values are not representative of effect over complete intervention period. For representation of effect of dynamic lighting for this outcome, see Fig. 5.

However, this was attributed to one care facility. The intervention did not affect the fragmentation of the rhythm in the remaining care facilities. Additionally, we found a clinically relevant decrease in depressive symptoms. The dynamic lighting reduced social avoidance, and hyperactive, irritable and lethargic behaviour. Also, small effects were seen making sleep onset time and mid-sleep earlier, though the clinical relevance is limited. No adverse effects were observed.

The detrimental effect of lighting on stability of the sleep–wake rhythm should be interpreted with care. The initial analyses showed a worsening of the stability over weeks, which could be attributed to one care facility. This facility did not differ from the other five facilities in the baseline characteristics or baseline scores. When excluding this care facility from the analyses, dynamic lighting did not significantly affect the stability of the sleep–wake rhythm, though it is not clear whether this is due to the decrease in the sample size by 25% or represents a true lack of effect. The worsening of the stability in the excluded group home might have been the results of a changing care regime or a change in daily activities provided at the group home. We checked for major events or changes in care during the intervention study, but we did not find anything to explain the difference between this care facility and the others. Something might have occurred that slipped our attention.

Contrary to the existing literature, we could not confirm our hypothesis that dynamic lighting would benefit the sleep–wake rhythm in older adults with ID living in care facilities. Enhancing light exposure was shown to be effective in stabilising the sleep–wake rhythm of patients with dementia (Van Someren *et al.* 1997), although another study also did not find an effect on stability or fragmentation (Figueiro *et al.* 2014). Additionally, unlike previous findings in home-dwelling older adults and older adults in healthcare organisations, we did not find an effect of dynamic lighting on sleep efficiency (Figueiro *et al.* 2014) and sleep duration (Riemersma-Van Der

Lek *et al.* 2008; Figueiro *et al.* 2014), nor did we find an effect on the occurrence of sleep problems. However, there are few intervention studies on whole-day light exposure in care organisations that used the same outcomes, which makes a comprehensive comparison challenging.

Regulation of care in care facilities for people with ID might explain the lack of a beneficial effect of light on sleep–wake rhythm, sleep efficiency and sleep duration. Bedtimes are often scheduled based on pragmatic reasons and do not take into account the personal preferences, sleep pressure and tiredness of the residents. Maintaining the same care routine might have diminished the potential full effect of dynamic lighting. The effect of dynamic lighting might be more pronounced if residents' personal sleep–wake preferences were taken into consideration more.

Care dependency is not limited to sleep alone; older adults with ID depend on others such as care professionals to undertake all sorts of activities during the day, such as going on walks and doing crafts. These activities induce the accumulation of sleep pressure, or sleepiness, needed for falling asleep and maintaining sleep (Borbely *et al.* 2016). The level of activity (M10) during the day did not increase, and difficulties maintaining nightly sleep (WASO) remained unchanged. Thus, in addition to sufficient light exposure, addressing physical activity during the day and maintaining healthy sleep hygiene should be part of the prevention and treatment of sleep problems.

We found a large and clinically relevant decrease in depressive symptoms and a reduction in the probability of scoring above cut-off for depressive symptoms after placement of the light installation. These results are in line with a study on the effect of conventional bright light therapy on depressive symptoms in adults with ID (Hamers *et al.* 2020). Unlike the participants in the current study, the participants in that study were selected based on the presence of depressive symptoms, which makes the current findings even more remarkable. The reduction in depressive symptoms was almost twice the magnitude previously seen in older adults with Alzheimer's dementia, (36% vs 19% reduction (Riemersma-Van Der Lek *et al.* 2008). Furthermore, the decrease we found in agitated behaviour is also commonly seen in people with dementia (Figueiro *et al.* 2014; Wahnschaffe *et al.* 2017). This decline might be related to the decline in depressive symptoms, as agitation is often seen in depression in ID (Matson *et al.* 1999; Tsiouris 2001). Even though we did not select participants based on mood complaints, our results suggest that environmental dynamic lighting might be a promising intervention for mood disorders in people with ID.

The decrease of depressive symptoms in combination with the advancing of sleep onset time and mid-sleep by about 15 min could support the bidirectional relationship between sleep and depression (Legates *et al.* 2014; Bao *et al.* 2017; De Feijter *et al.* 2021) and more specific the hypothesis of the antidepressant effect of advancing the circadian rhythm (Wehr *et al.* 1979), a 5–6-h advance of sleep onset and wake time to decrease depressive symptoms in patients with major depression (Wehr *et al.* 1979; Souetre *et al.* 1987). Following this hypothesis, an advancing effect in the morning is expected but not supported by the results of our study, as final wake times or onset of M10 did not change. In practice, it seems that the residents of this study slept in earlier, which resulted in longer time in bed rather than advancing the circadian rhythm. Therefore, we hypothesise that the advancing effect of light on sleep onset and mid-sleep was merely a results of the behavioural response to the cue of the dimmed light, rather than the advancing of the circadian phase.

Strengths and limitations

The current study is the first large high-quality study, using an innovative study design, on environmental dynamic lighting as an intervention for the improvement of sleep–wake rhythm, sleep, mood and behaviour in older adults with ID. As we did not select participants based on depressive symptoms, the improvement in mood suggests that environmental dynamic lighting might be an even more valuable contribution for populations with known mood complaints. Using the ceiling-mounted dynamic light installation, light reaches the lower retina, which is thought to be more effective in stimulating the circadian rhythm when compared with administering bright light therapy with a light box (Glickman *et al.* 2003). Another strength is that we planned the current study around the winter solstice in order to

measure the independent effect of enhancing light exposure.

A limiting factor is that our sample might not be representative for all older adults with ID living in care facilities. Compared with a large cohort of older adults with ID [HA-ID study (Hilgenkamp *et al.* 2011)], our sample was relatively mobile and had a higher prevalence of depressive symptoms [23 vs 17% (Hermans *et al.* 2013)] and did not include many participants with severe or profound ID. As severe and profound ID co-occurs with severe neurological and physical disabilities that affect sleep too, this might limit the effect of increasing light exposure on sleep in adults with severe to profound ID in comparison with adults with mild to moderate ID. Therefore, our results can only be generalised to older adults with mild to moderated level of ID; future studies are necessary to study the effect of light on sleep and mood in older adults with severe and profound ID.

Another limitation is the lack of reliable data on personal (day)light exposure prior and during the intervention. Initially, personal light measurements were taken every measurement week using a Hobo data logger (Onset Computer Corporation 2018). Despite that using the Hobo data logger was shown to be feasible in our population before (van Duijnhoven *et al.* 2017), the amount of missing data on light exposure in our study was high (up to 51%) due to wearing these light sensors incorrectly, for example, underneath sweaters and jackets (Böhmer *et al.* 2021b). This made it impossible to report reliable data on personal daily light exposure during the study period. In future research, the reliability of (day)light exposure measurements could be increased by using two light sensors, one on a broche above the clothing worn inside and one on the jacket worn outside (Itzhacki *et al.* 2019; te Lindert *et al.* 2018).

In this study, professional caregivers reported on mood and behaviour of the participants, while they might be affected by the light themselves too. Dynamic light might have had an effect on the caregivers, which might have affected how they perceived and rated the behaviour of the participants. Therefore, future studies should take the effect of the dynamic light on the professional caregivers into account.

The current study took place around the December holidays. Clinical experience shows that the weeks prior to the holidays and the holidays themselves are stressful for people with ID living in a care facility. Therefore, in combination with the installation of the dynamic lighting, the end of the stressful holiday period could have also resulted in improvements in the scores during the intervention. Despite the possible stressors, baseline scores were stable over 9 weeks, and the improvements during the intervention were stable and similar for the different groups. This implies that the effect is probably attributable to the light installation. Ideally, future research could aim to replicate these findings during different periods of the year to make sure the effects are a result of the light installation.

Clinical relevance

Environmental dynamic lighting might be a promising intervention for care facilities with specific target groups, such as people with behaviour problems and mood disorders. In addition, integrated dynamic lighting might help prevent sleep problems and mood complaints in people with ID. Evidence suggests that even in unaffected adults, increasing light exposure is associated with a better regulated sleep–wake rhythm (Böhmer *et al.* 2021a). Integrated dynamic lighting might be an undemanding and effective addition to prevent or treat of mood and/or sleep problems.

In this study, we increased environmental light exposure by installing a dynamic light installation. Ideally, taking a daily walk outside would be a desired activity providing both physical activity and light exposure. In practice, this is not achieved easily in care organisations due to practical, logistical and motivational reasons. Therefore, all additional actions to improve the sleep–wake rhythm and mood are welcome. With the current study, we provide an easy-to-implement, integrated, effective intervention to improve mood in people with ID.

Optimising the lit environment is essential for both maintaining a synchronised sleep–wake rhythm and perceiving the world around, especially in older adults with ID living in a care facility. With ageing and age-related conditions, the risk of falling increases (Rubenstein 2006; Ho *et al.* 2019), and falls in older people with ID are common (Ho *et al.* 2019; Pope *et al.* 2021). Increasing lighting in the living environment is associated with reducing the risk of

falls (Bicket *et al.* 2020). Furthermore, with the ageing of the eye and the yellowing of the lens, sufficient lighting is essential to perform everyday activities such as reading and doing crafts. Being able to perform these activities more easily might have contributed to a better mood, represented by a decrease in depressive symptoms. This remains a hypothesis, as the effect of increasing light on visual functioning and performing daily activities was not measured in the current study.

Conclusion

Enhancing environmental light exposure using dynamic lighting is an effective intervention that benefits mood and behaviour in older adults with ID living in care facilities. Integrated dynamic lighting is a promising, undemanding and potentially effective addition to improve mood and behaviour in care facilities for people with ID. Future research could focus on the long-term effects of dynamic lighting, study the optimal characteristics of the installation or target specific groups. Sleep disturbances in older adults with ID is a multifactorial problem that involves the whole day–night rhythm. The beneficial effects of the dynamic lighting might be more pronounced when care is adjusted to suit the personal preferences of the residents.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, M.N.B., upon reasonable request.

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Appendix 1

Full models

Stability	IS ~ time * intervention + sex + age + mobility + ADL_T01 + epilepsy, random = ~ 1 | participant
Fragmentation	IV ~ ns(time, df = 2) * intervention + sex + age + mobility + ADL_T01 + IADL_T01 + epilepsy + beta blockers, random = ~ ns(time, df = 2) | participant
L5	L5 ~ time + intervention + mobility + ADL_T01 + antidepressants + antipsychotics, random = ~ 1 | participant
L5 onset	L5onsetphase ~ time + intervention + daily activities (days per week) + benzodiazepines, random = ~ 1 | participant
M10	M10 ~ time + intervention + ADL_T01 + epilepsy + beta blockers, random = ~ ns(time, df = 2) | participant
M10 onset	M10onsetphase ~ time + intervention + daily activities (hours per week) + benzodiazepines, random = ~ 1 | participant
Amplitude	AMP ~ time + intervention + ADL_T01 + IADL_T01 + mobility + epilepsy + beta blockers, random = ~ 1 | participant
Relative Amplitude	RA ~ time + intervention + antidepressants + antipsychotics + ADL_T01, random = ~ 1 | participant
Sleep estimates	
Total sleep time	TST ~ date + intervention + age + sex + IADL_T01 + ADL_T01 + daily activities (hours per week) + benzodiazepines + antipsychotics + epilepsy, random = ~ ns(date, df = 2) | participant
Waking after sleep onset	WASO ~ date + intervention + age + mobility + IADL_T01 + ADL_T01 + daily activities (days per week) + benzodiazepines + antipsychotics + antiepileptic's + hearing impairment + genetic syndrome + assumed sleep, random = ~ ns(date, df = 2) | participant
Sleep efficiency	SE ~ date + intervention + age + sex + mobility + IADL_T01 + ADL_T01 + daily activities (days per week) + benzodiazepines + antipsychotics + antiepileptic's + epilepsy + hearing impairment + genetic syndrome, random = ~ ns(date, df = 2) | participant
Sleep onset	SOT ~ ns(date, df = 2) * intervention + age + sex + ADL_T01 + daily activities (hours per week) + benzodiazepines + antipsychotics + antiepileptics + epilepsy + hearing impairment + genetic syndrome + level of ID + betablockers, random = ~ ns(date, df = 2) | participant
Final wake time	FWT ~ date + intervention + age + mobility + IADL_T01 + ADL_T01 + daily activities (hours per week) + benzodiazepines + antiepileptics, random = ~ ns(date, df = 2) | participant
Mid-sleep	Midsleep ~ ns(date, df = 2) * intervention + age +s + IADL_T01 + ADL_T01 + daily activities (hours per week) + benzodiazepines + antipsychotics + antiepileptics + betablockers + hearing impairment, random = ~ 1 | participant
Number of sleep bouts	Numberofsleepbouts ~ date + intervention + age + mobility + IADL_T01 + ADL_T01 + daily activities (hours per week) + betablockers + antipsychotics + genetic syndrome + hearing impairment, random = ~ ns(Date, df = 2) | participant
Sleep bout duration	Meansleepbouttimemin ~ date + intervention + age + sex + Level of ID + mobility + ADL_T01 + daily activities (hours per week) + betablockers, random = ~ ns(date, df = 2) | participant

(Continued)

Number of wake bouts	Numberofwakebouts ~ date + intervention + age + sex + IADL_T01 + ADL_T01 + antipsychotics + betablockers + benzodiazepines + genetic syndrome + hearing impairment, random = ~ ns(Date, df = 2) | participant
Wake bout duration	Meanwakebouttimemin ~ date + intervention + age + sex + mobility + IADL_T01 + ADL_T01 + daily activities (days per week) + benzodiazepines + epilepsy, random = ~ ns(Date, df = 2) | participant
Short sleep	Shortsleep ~ date + intervention + age + ADL_T01 + IADL_T01 + daily activities (days per week) + antipsychotics, family = binomial(), id = participant, corstr = "exchangeable"
Night waking	Nightwaking ~ date + intervention + age + sex + mobility + ADL_T01 + IADL_T01 + daily activities (days per week) + antipsychotics + benzodiazepines, family = binomial, id = participant, corstr = "exchangeable"
ADAMS	
Depressive symptoms	ADAMS_Depression ~ time + intervention + age + sex + antipsychotics + epilepsy, random = ~ ns(time, df = 2) | participant
Anxiety symptoms	ADAMS_Anxiety ~ time + intervention + IADL_T01 + antipsychotics, random = ~ 1 | participant
Social avoidance	ADAMS_Social_Avoidance ~ time + intervention + sex + mobility + ADL_T01 + IADL_T01 + antipsychotics, random = ~ time | participant
Other symptoms	-
Screening Depression	ScreeningDepression ~ time + intervention + daily activities (days per week) + antipsychotics, family = binomial(), id = participant, corstr = "exchangeable"
Screening Anxiety	ScreeningAnxiety ~ time + intervention + antipsychotics, family = binomial(), id = participant, corstr = "exchangeable"
ABC	
Hyperactivity	ABC_Hyperactivity ~ time + intervention + antipsychotics + epilepsy + benzodiazepines, random = ~ ns(time, df = 2) | participant
Irritability	ABC_Irritability ~ time + intervention + daily activities (days per week) + antipsychotics + epilepsy + benzodiazepines, random = ~ ns(time, df = 2) | participant
Lethargy	ABC_Lethargy ~ time + intervention + daily Activities (days per week) + antipsychotics + epilepsy + benzodiazepines, random = ~ time | participant
Inadequate speech	ABC_Inadequate_speech ~ ns(time, df = 2) * intervention + antipsychotics + mobility, random = ~ 1 | participant
Stereotypy	-

Full test results of models with non-linear term (natural spline, df = 2) for time and/or interaction for time and intervention

Fixed effects: IS ~ time * Intervention + Sex + Age + Mobility + Barthel_T01 + Epilepsy

	Value	Std. error	DF	t value	P value
(Intercept)	0.3730249	0.2604854	117	1.4320376	0.1548
time	0.0057876	0.0024283	117	2.3833700	0.0188
Intervention	0.1072920	0.04184390	117	2.5641022	0.0116
Sex female	0.0403991	0.04829016	31	0.8365910	0.4092
Age	0.0012538	0.00305032	31	0.4110536	0.6839
Mobility with support	−0.0756427	0.07959848	31	−0.9503031	0.3493
Mobility wheelchair	0.0516261	0.09218538	31	0.5600252	0.5795
Barthel_T01	0.0114818	0.00590995	31	1.9428009	0.0612
Epilepsy	−0.0828045	0.06319795	31	−1.3102411	0.1997
time:intervention	−0.0082066	0.00273661	117	−2.9988331	0.0033

Fixed effects: IV ~ ns(time, df = 2) * Intervention + Sex + Age + Mobility + Barthel_T01 + Lawton_T01 + Epilepsy + Beta blockers

	Value	Std. error	DF	t value	P value
(Intercept)	0.6988945	0.3493700	115	2.000442	0.0478
ns(time, df = 2)1	0.1523786	0.2090815	115	0.728800	0.4676
ns(time, df = 2)2	0.6164107	0.4465877	115	1.380268	0.1702
Intervention	−0.5087580	0.2311909	115	−2.200597	0.0298
Sex	10.0475728	0.0655067	29	0.726227	0.4735
Age	0.0022832	0.0041903	29	0.544877	0.5900
Mobility with support	0.1702592	0.1074155	29	1.585053	0.1238
Mobility wheelchair	−0.1518288	0.1384362	29	−1.096742	0.2818
Barthel_T01	−0.0342962	0.0095723	29	−3.582860	0.0012
Lawton_T01	0.0217176	0.0137927	29	1.574574	0.1262
Epilepsy	0.3356144	0.0897508	29	3.739402	0.0008
Beta blockers	−0.1127678	0.0972523	29	−1.159539	0.2557
ns(time, df = 2)1:Intervention	0.7068088	0.4530172	115	1.560225	0.1215
ns(time, df = 2)2:Intervention	−0.4399246	0.4513825	115	−0.974616	0.3318

Fixed effects: SOT ~ ns(date, df = 2) * Intervention + Age + Sex + Barthel_T01 + Daily activities (hours per week) + Benzodiazepines + Antipsychotics + Anti epileptics + Epilepsy + Hearing impairment + Genetic syndrome ID + Level of ID + Beta blockers

	Value	Std. error	DF	t value	P value
(Intercept)	87341.99	6805.054	922	12.834871	0.0000
ns(date value, df = 2)1	−2187.33	2873.951	922	−0.761089	0.4468
ns(date value, df = 2)2	−14789.27	6621.930	922	−2.233378	0.0258
Intervention1	4155.90	3884.406	922	1.069894	0.2849
Age	−104.77	73.304	22	−1.429282	0.1670
Sex1	−1191.37	1226.445	22	−0.971403	0.3419
Barthel_T01	252.92	105.624	22	2.394513	0.0256
Daily activities (hours per week)	−97.85	74.410	22	−1.315022	0.2020

(Continued)

Fixed effects: SOT ~ ns(date, df = 2) * Intervention + Age + Sex + Barthel_T01 + Daily activities (hours per week) + Benzodiazepines + Antipsychotics + Anti epileptics + Epilepsy + Hearing impairment + Genetic syndrome ID + Level of ID + Beta blockers

	Value	Std. error	DF	*t* value	*P* value
Benzodiazepines yes	1730.18	1287.872	22	1.343439	0.1928
Antipsychotics	−2706.55	1188.428	22	−2.277418	0.0328
Antiepileptics	−1815.25	2119.905	22	−0.856289	0.4011
Epilepsy	−468.14	1885.187	22	−0.248326	0.8062
Hearing impairment	267.77	658.602	22	0.406580	0.6882
Genetic syndrome Down syndrome	−194.71	1673.428	22	−0.116352	0.9084
Genetic syndrome Fragile X	−888.29	3734.738	22	−0.237846	0.8142
Genetic syndrome no/unknown	62.63	2611.155	22	0.023986	0.9811
Level of moderate	−3796.38	1819.229	22	−2.086809	0.0487
Level of severe	−1771.41	1609.971	22	−1.100272	0.2831
Level of ID unknown	−9876.22	5522.385	22	−1.788397	0.0875
Beta blockers1	199.61	1686.169	22	0.118381	0.9068
ns(date, df = 2)1:Intervention	−4000.21	7323.613	922	−0.546208	0.5851
ns(date, df = 2)2:Intervention	14325.53	6726.808	922	2.129618	0.0335

Fixed effects: Mid-sleep ~ ns(date, df = 2) * Intervention + Age + Sex + Lawton_T01 + Barthel_T01 + Daily activities (hours per week) + Benzodiazepines + Antipsychotics + Antiepileptics + Beta blockers + Hearing impairment

	Value	Std. error	DF	*t* value	*P* value
(Intercept)	101858.58	5129.496	922	19.857426	0.0000
ns(date, df = 2)1	−1135.57	2038.615	922	−0.557031	0.5776
ns(date, df = 2)2	−8775.37	4687.883	922	−1.871927	0.0615
Intervention	3423.16	2884.311	922	1.186822	0.2356
Age	−20.63	59.139	28	−0.348836	0.7298
Sex female	34.74	1066.316	28	0.032577	0.9742
Lawton_T01	−239.91	178.432	28	−1.344545	0.1896
Barthel_T01	63.58	106.358	28	0.597759	0.5548
Daily activities (hours per week)	−128.47	58.589	28	−2.192769	0.0368
Benzodiazepines	1815.18	974.812	28	1.862085	0.0731
Antipsychotics	−1343.87	1042.558	28	−1.289009	0.2079
Antiepileptics	−1395.43	1670.243	28	−0.835464	0.4105
Beta blockers	−182.78	1361.328	28	−0.134266	0.8942
Hearing impairment	−85.20	344.043	28	−0.247646	0.8062
ns(date, df = 2)1:Intervention	−4191.01	5564.238	922	−0.753205	0.4515
ns(date, df = 2)2:Intervention	8367.79	4842.570	922	1.727966	0.0843

Fixed effects: Meanwakebouttimemin ~ ns(date, df = 2) * Intervention + Age + Sex + Mobility + Lawton_T01 + Barthel_T01 + Daily activities (days per week) + Benzodiazepines + Epilepsy

	Value	Std. error	DF	*t* value	*P* value
(Intercept)	0.591646	1.2962233	981	0.4564385	0.6482
ns(date, df = 2)1	−1.009352	1.0395716	981	−0.9709306	0.3318
ns(date, df = 2)2	−2.383821	2.0155160	981	−1.1827347	0.2372

(Continued)

Fixed effects: Meanwakebouttimemin ~ ns(date, df = 2) * Intervention + Age + Sex + Mobility + Lawton_T01 + Barthel_T01 + Daily activities (days per week) + Benzodiazepines + Epilepsy

	Value	Std. error	DF	*t* value	*P* value
Intervention	−2.087531	1.1072613	981	−1.8853103	0.0597
Age	0.006828	0.0144511	31	0.4725066	0.6399
Sex female	−0.107644	0.2639739	31	−0.4077845	0.6862
Mobility with support	0.958049	0.3370689	31	2.8422954	0.0079
Mobility wheelchair	0.011635	0.4670052	31	0.0249150	0.9803
Lawton_T01	0.006192	0.0513241	31	0.1206547	0.9047
Barthel_T01	0.032095	0.0345088	31	0.9300421	0.3595
Daily activities (days per week)	−0.010329	0.0827811	31	−0.1247796	0.9015
Benzodiazepines	−0.238601	0.2463854	31	−0.9684069	0.3403
Epilepsy	0.532300	0.3279498	31	1.6231142	0.1147
ns(date, df = 2)1:Intervention	5.527216	2.1102456	981	2.6192286	0.0089
ns(date, df = 2)2:Intervention	3.344202	2.0313633	981	1.6462847	0.1000

Appendix 2

Test results of effect of dynamic lighting on adverse events

		Baseline, mean (SD)			Intervention, mean (SD)			Linear mixed model analysis effect of dynamic lighting[a]					
		1.00	2.00	3.00	4 (3rd week after installation)	5 (7th week after installation)	6 (14th week after installation)	Valid obs	*N*	Beta	5%	95%	*P* value
		(*n* = 49)	(*n* = 48)	(n = 46)	(*n* = 49)	(*n* = 49)	(*n* = 52)						
Dizziness	Range, 0–3	0.61 (0.9)	0.7 (1.07)	0.45 (0.75)	0.38 (0.75)	0.3 (0.65)	0.4 (0.72)	252	52	−0.14	−0.35	0.08	0.20
Drowsiness	Range, 0–3	1.3 (1.06)	1.37 (1.06)	1.19 (0.93)	0.97 (0.92)	1.14 (0.97)	0.98 (0.95)	252	52	−0.18	−0.63	0.02	0.26
Eye complaints	Range, 0–3	0.79 (1.06)	0.83 (1.13)	0.93 (1.04)	0.55 (0.93)	0.65 (0.99)	0.73 (1.03)	252	52	−0.35	−0.65	−0.04	0.03*
Feebleness	Range, 0–3	0.85 (0.95)	1.16 (1.07)	0.8 (0.85)	0.67 (0.89)	0.77 (0.98)	0.71 (0.97)	252	52	−0.30	−0.63	0.023	0.07
Headache	Range, 0–3	0.67 (0.87)	0.91 (1)	0.78 (0.84)	0.93 (1)	0.61 (0.75)	0.84 (1.01)	252	52	−0.02	−0.32	0.27	0.88
Hunger	Range, 0–3	1 (0.93)	0.68 (0.87)	0.78 (0.89)	0.59 (0.78)	0.65 (0.8)	0.71 (0.89)	252	52	−0.12	−0.42	0.18	0.43
Hyperactivity	Range, 0–3	0.38 (0.73)	0.41 (0.87)	0.39 (0.71)	0.2 (0.53)	0.22 (0.58)	0.42 (0.82)	252	52	−0.31	−0.54	−0.09	0.01*
Inability to sleep	Range, 0–3	0.65 (0.83)	0.79 (0.89)	0.8 (0.83)	0.65 (0.85)	0.73 (0.86)	0.71 (0.93)	252	52	−0.20	−0.48	0.09	0.17
Irritability	Range, 0–3	1.16 (1)	1.39 (1.18)	1.3 (1.07)	1.04 (1.07)	1.16 (1.14)	1.38 (1.22)	252	52	−0.33	−0.62	−0.03	0.03*
Nausea	Range, 0–3	0.46 (0.76)	0.41 (0.76)	0.54 (0.78)	0.34 (0.63)	0.34 (0.69)	0.25 (0.47)	252	52	−0.09	−0.33	0.15	0.47
Constipation	Range, 0–3	0.73 (0.97)	0.81 (1)	0.91 (0.98)	0.59 (0.76)	0.71 (0.88)	0.63 (0.79)	252	52	−0.29	−0.57	−0.01	0.046
Nervous	Range, 0–3	1.02 (1.01)	1.25 (1.06)	1.23 (1.01)	0.97 (1.03)	1.12 (0.99)	1.26 (1.01)	252	52	−0.30	−0.58	−0.03	0.03*
Anxious	Range, 0–3	0.91 (0.99)	1.08 (0.98)	0.93 (0.99)	0.89 (1)	1 (1.02)	1 (1)	252	52	−0.05	−0.35	0.24	0.72
Stomachache	Range, 0–3	0.75 (0.99)	0.85 (1.09)	0.89 (1.01)	0.69 (0.84)	0.79 (1.11)	0.69 (0.96)	252	52	−0.07	−0.35	0.21	0.61
Sweating	Range, 0–3	0.57 (0.91)	0.47 (0.71)	0.54 (0.86)	0.38 (0.75)	0.26 (0.63)	0.38 (0.74)	252	52	−0.12	−0.02	0.02	0.32
Trembling hands	Range, 0–3	0.55 (0.91)	0.54 (0.94)	0.56 (0.91)	0.4 (0.81)	0.32 (0.77)	0.48 (0.87)	252	52	−0.14	−0.37	0.10	0.25
Other complaints	Range, 0–3	0.65 (1.01)	0.54 (0.98)	0.78 (1.15)	0.36 (0.88)	0.32 (0.77)	0.63 (0.97)	252	52	−0.38	−0.69	−0.08	0.01*

*$P < .05$.

N, participants; SD, standard deviation; Valid obs, Valid observations.

[a]Linear mixed model analysis adjusted for time, test results presented for intervention (dynamic lighting).