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the light side

Light, sleep and
mood in older adults
with intellectual disabilities

Mylène Böhmer

The Light Side
Light, sleep and mood
in older adults
with intellectual disabilities

Mylène Nathalie Böhmer



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The Light Side
Light, sleep and mood
in older adults with intellectual disabilities

De lichte kant
Licht, slaap en stemming
bij ouderen met een verstandelijke beperking

Proefschrift

ter verkrijging van de graad van doctor aan de
Erasmus Universiteit Rotterdam
op gezag van de
rector magnificus

Prof. dr. A.L. Bredenoord

en volgens besluit van het College voor Promoties.
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Prof. dr. P.J.E. Bindels
Prof. dr. E.J.W. van Someren

Overige leden:

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Dr. A. Oppewal

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1

General Introduction

GENERAL INTRODUCTION

My fascination for sleep started with an innate talent for (excessive) sleeping and a deep appreciation for a good night of sleep. My professional interest started with an inspiring professor Psychophysiology during the first year of studying Psychology. Over the course of my professional life, I noticed how often people would downplay their sleep problems and would just accept them. This despite the fact that science continuously shows the importance of good sleep to stay healthy. Good sleep is especially important for frail populations like older adults with intellectual disabilities (ID).

In this chapter, after some background information on intellectual disability, sleep and the importance of light exposure to regulate sleep, we will discuss sleep in older adults with ID, followed by the current state of evidence on light exposure as treatment to improve sleep in ID and the aims and outline of this thesis.

Intellectual Disability

An intellectual disability is characterized by a combination of limitations in both intellectual (IQ<70) and adaptive functioning, which originates before the age of 18¹. The etiologies of ID are often genetic- or chromosomal disorders, perinatal problems, an acquired condition in early childhood or a combination of these factors. The prevalence of ID (IQ<70) lies around 1% worldwide². In 2018, there were approximately 440.000 people with ID in the Netherlands. It was estimated that 111.000 people with ID were registered to receive care and support financed by the Long-term Care Act of the Dutch social security system³. In 2018, 63.000 people with ID lived in a Dutch care facility⁴ where they received up to 24 hour guidance and care with day to day activities like personal care, meals, bedtime, work- and daytime activities.

Circadian rhythms and light

Much of all human physiology and behavior follows a circadian rhythm, a rhythm that displays an oscillation of about 24 hours. Circadian rhythms are found in, for example, heart rate, body temperature, hormone secretion, alertness, mood regulation, and the sleep-wake rhythm⁵. These 24-hour rhythms are driven by a circadian clock which lies in the suprachiasmatic nucleus (SCN) in the hypothalamus of the midbrain. Circadian rhythms are self-sustained or endogenous which means that they are always present. Although always present, the rhythms are entrained to the natural light-dark cycle by external cues called *Zeitgebers* (German for “time-givers”)⁶. The most important *Zeitgeber* for the

circadian rhythm is (sun)light⁷. Light enters the eye which acts on the intrinsic photosensitive retinal ganglion cells (ipRGC), which project to the SCN through the retina-hypothalamic tract⁸.

Given that light is the most important *Zeitgeber*, light is potentially also the biggest disruptor of circadian rhythms⁹. Disruption of circadian rhythms associated with light exposure at the wrong time of day is seen in jet lag¹⁰ and shift work¹¹. In these cases, the SCN is presented with light at a time that is out of sync with the internal circadian clock. In the general population, insufficient or badly timed light exposure is related to disrupted sleep^{12,13}, lower sleep quality¹⁴ and mood complaints¹⁵⁻¹⁸. Overall, proper alignment between environmental light and the internal circadian clock is considered essential for survival¹⁹.

Sleep-wake rhythm, sleep and sleep problems

One of the most studied rhythms is the sleep-wake rhythm. Regulation of the sleep-wake rhythm is described by the two-process model²⁰, which posits an interaction between the homeostatic- and circadian process of the sleep-wake rhythm. The homeostatic process (process 'S') entails the sleep pressure, or tiredness, that builds up during the day with increasing time awake. Activities that may enhance the buildup of sleep pressure are for instance walking, cycling, doing crafts or household chores. Process 'S' interacts with process 'C' that describes the circadian component of the sleep-wake rhythm, as explained previously. This model emphasizes that behavior, and more specific physical activity during the day is as important as circadian alignment for a properly regulated sleep-wake rhythm.

Sleep has been defined as a reversible behavioral state of perceptual disengagement from, and unresponsiveness to, the environment²¹. Different sleep stages can be identified: light sleep (N1, N2), deep- or restorative sleep (N3) and Rapid-eye movement- or dream-sleep (REM-sleep). These stages follow each other in 90-to-120-minute cycles, with four or five cycles per night. Sleep is a complex brain function, and can be visualized by the impressive brain wave patterns of the different sleep stages using the golden standard to measure sleep; polysomnography (PSG).

With aging, changes in sleep and its architecture occur; older adults often report waking up earlier, sleeping early and/or short, having troubles with maintaining sleep during the night, and a tendency to nap during the day^{22,23}. These changes might be a result of the age-related increasing fragmentation of the circadian sleep-wake rhythm²⁴. With aging, the sensitivity of the SCN for light as *Zeitgeber* decreases as the neurons decrease in number²⁵, which is hypothesized to explain the increasing prevalence of sleep problems in older adults²⁶.

Although we are not sure about the exact function of nocturnal sleep, we do know what happens when someone sleeps poorly. Poor sleep can manifest itself by troubles with settling and maintaining sleep during the night, by short sleep, and waking up early. These problems result in a low sleep quality, often measured with the well validated Pittsburg Sleep Index²⁷. Both sleep problems and poor sleep quality are associated with health-related conditions, like diabetes, heart disease, cancer and mood disorders²⁸⁻³¹. Further, poor sleep affects quality of life and well-being³⁰, and is associated with increased mortality³².

The HA-ID study and sleep-wake rhythm in older adults with ID

Subjective sleep data show that sleep problems are prevalent throughout the entire lifespan of in people with ID. Parents and caregivers report that sleep problems are present in up to 42% of children with ID³³⁻³⁵, and are more common than among their typically developing peers^{36,37}. A survey among adults with ID revealed that sleep problems were prevalent in 79.3% of the sample³⁸. Self-reporting sleep problems requires the cognitive ability of self-reflection, which is often affected in people with ID. Professional caregivers often have an incomplete picture what happens during sleep, as people with ID might lie awake for hours without the caregivers knowing. Therefore subjective, self-reported or informant reported sleep problems might result in underdiagnosing sleep problems in people with ID.

The “Healthy aging in people with ID” (HA-ID) study was the first to objectively measure the sleep-wake rhythm in older adults with ID (>50 years). The HA-ID study was a large cohort study aimed to characterize health status, and to determine unique disease risks and trajectories of older adults with ID³⁹. Results of the HA-ID study showed that the circadian sleep-wake rhythm of older adults with ID is unstable and fragmented⁴⁰, and sleep problems are common in up to 72% of older adults with ID living within health care facilities⁴¹. Overall, nocturnal sleep in older adults with ID typically involves lying in bed for 10.5 hours, lying awake during the night for about two hours and having a low sleep efficiency of about 70%⁴¹. Nocturnal wakefulness and short sleep are the most common sleep problems in older adults with ID, next to disrupted settling and waking up early⁴¹.

The etiology of sleep problems in people with ID is merely unclear. Some genetic syndromes associated with ID show clear consequences that could contribute to disrupted sleep, for instance the inverted melatonin profile in Smith-Magenis Syndrome⁴². Prader-Willi syndrome is associated with sleep-related breathing disorders and problems maintaining sleep⁴³, whereas in Angelman syndrome insomnia and general sleep difficulties are common^{43,44}. However,

in most cases the etiology of both ID as well as the sleep problems is unknown. It is hypothesized that as regulation of the circadian rhythm is a complex brain function, this might be affected in ID just like their other brain functions, and that people with ID are therefore at higher risk for sleep problems⁴⁵.

Diagnosis and treatment of sleep problems in people with intellectual disabilities

Diagnosis of sleep problems in people with ID ideally entails the combination of (hetero)anamneses, both subjective as well as objective sleep diagnostics. Interviewing patients, and their (professional) caregivers is a first step to investigate sleep. Second, validated questionnaires on sleep can be used, for instance the Sleep Questionnaire (SQ-SP)⁴⁶ was validated to explore sleep problems in people with ID⁴⁷. With regard to the objective measurements, PSG is the golden standard to objectify sleep, but is it often not accepted by people with more severe ID. Previously, actigraphy was found to be a feasible and reliable alternative for PSG to measure sleep in people with ID⁴⁸. Actigraphy is conducted using a wrist-worn accelerometer that measures the combination of intensity, amount and duration of activity based on which the software can analyze the sleep-wake rhythm and sleep parameters.

The treatment of sleep problems follows a stepped-care model that moves from sleep hygiene, and behavioral interventions towards pharmacological interventions. Good sleep hygiene prescribes daily routines, timely light exposure and a bedroom environment that supports a good night of sleep. Second, behavioral interventions, for instance stimulus control, sleep restriction, relaxation therapy and cognitive behavior therapy, are focused on changing the behavior in order to teach individuals to fall asleep and maintain sleep during the night. Personalized sleep hygiene and behavioral interventions have shown to improve sleep in children and adults with ID by sleep wake scheduling, change timing of routines and increasing daytime activities^{49,50}. Pharmacological treatment for sleep problems with, for instance, melatonin or sedatives, is considered a last resort. Although more high quality studies are needed, the few studies reported show a large beneficial effect of sleep hygiene improvement and behavioral interventions on sleep in people with ID^{51,52}.

Light treatment for sleep problems and depressive symptoms

Many studies have been published about the effect of light on the circadian rhythms, with a focus on how changes in environmental light intensity affect the circadian rhythmicity of sleep and mood¹⁹. As insufficient or badly timed light exposure is associated with sleep- and mood problems, has also been used

as a treatment for these problems. Conventional Bright light therapy (>10.000 lux) is administered using a light box placed 20-30 cm in front of the user, where the user has to sit behind for a period of maximum an hour. Bright light treatment can also be an effective treatment for sleep problems⁵³ and (non-) seasonal depression^{54,55}, both in the general population and in hospitalized people^{56,57}.

With the increasing awareness of the beneficial effect of light on sleep and mood, the importance of sufficient environmental lighting in health care facilities grew as well. Increasing the environmental light intensity using ceiling mounted light installations has shown to be effective in improving the sleep-wake rhythm and sleep in older adults⁵⁸ and older adults with dementia⁵⁸⁻⁶³. Additionally, enhancing environmental light intensity showed to be effective in reducing depressive symptoms in people suffering from dementia^{61,64,65}.

Studies on how increasing the light intensity affects sleep and mood in older adults with ID are scarce. One case report showed that increasing daytime natural light exposure was effective in stabilizing the sleep-wake rhythm in a 34-year-old man with ID⁶⁶. Recently, conventional bright light therapy showed promising results for reducing depressive symptoms in adults with ID⁶⁷, which are present in 17% of older adults with ID⁶⁸. No reports have been published on the effect of light exposure on sleep and sleep problems in people with ID. This raised our interest in the possibility to apply light to improve sleep and mood in older adults with ID.

Light exposure in older adults with ID is particularly of interest as the living environment of people with ID is often poorly lit. Jelluma et al. (2012) compared the environmental light intensity in these health care facilities with the European lighting guidelines EN 12464-1:2003 for safety and optimal visual functioning in the working environment⁶⁹. These guidelines prescribe an illuminance level on a table or desk of 1000 lux and 200 lux for the hallway (EN 12464-1:2003). Jelluma et al. concluded that lighting in health care facilities for people with ID reached these guidelines only in 3,3 to 6,5 % of the measurements⁶⁹.

Taking all together, given 1) the high prevalence of sleep problems in older adults with ID, 2) the suboptimal lighting conditions in living environment for people with ID and 3) the beneficial effect of enhancing light exposure on sleep and mood in other populations, the aim of the current dissertation is to study the relationship between light exposure and sleep in older adults with ID living in a care facility. Additionally, given the beneficial effects of increasing light exposure on depressive symptoms in other populations, we will explore relationship between light exposure and mood in older adults with ID as well.

In the transition from “what works” to “what works best” in care for people with ID, scientific research is conducted by- and in collaboration with the care

providers for people with an ID. Following this development, this dissertation is the result of the collaboration between Middin, a Dutch care provider for people with intellectual disabilities and the research group of Intellectual Disability Medicine of Erasmus Medical Center Rotterdam, the Netherlands.

Study aims and outline of thesis

The aim of the current dissertation is to study the relationships between light exposure, sleep and mood in older adults with ID living in a care facility.

First, although the HA-ID study described the prevalence of sleep problems in older adults with ID, it remained unclear how these relate to the prevalence of sleep problems in older adults from the general population. Therefore, by comparing sleep-data of the HA-ID study with data from a large cohort study on sleep in community-dwelling older adults we aimed to describe both the prevalence and severity of sleep problems in older adults with ID (*chapter 2*).

Insufficient light exposure is assumed to be related to a wide array of health problems. Evidence on the relationship between light, sleep-wake rhythm and mood is provided by both fundamental studies in humans and studies in populations with extreme deviating light exposure patterns. Few studies focus on the role of whole-day light exposure in the habitual setting and the association with these health problems. Therefore, we performed a systematic literature review that aimed to describe the association between light exposure and sleep-wake rhythms and mood in the general population (*chapter 3*).

Next, we focused on personal daily light exposure in older adults with ID. Insufficient light exposure in the living environment might be compensated by outdoor illuminances. Therefore, we aimed to describe the continuously measured personal light exposure pattern during the waking day in older adults with ID living in care facilities. In addition, we explored whether light exposure of older adults with ID meet the thresholds of light intensities associated with better mood and sleep (*chapter 4*).

Finally, we studied increasing environmental light exposure as possible treatment to improve sleep and mood in older adults with ID living in care facilities. We installed environmental dynamic lighting in common living rooms of group homes. We aimed to assess the effect of light on sleep-wake rhythm, sleep problems, mood, behaviour and adverse events in older adults with ID during the first 14 weeks (*chapter 5*) and one year (*chapter 6*) after installing the dynamic light.

In the final chapter (*chapter 7*) we reflect on the main findings of this thesis. Implications for clinical practice and directions for future research are discussed.

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2

Comparison of sleep-wake rhythms in older adults with intellectual disabilities and the general population

Mylène N. Böhmer, Alyt Oppewal, Patrick J.E. Bindels ,
Henning Tiemeier, Eus J.W. van Someren, Dederieke A.M.
Festen

Böhmer MN, Oppewal A, Bindels PJE, Tiemeier H, van Someren
EJW, Maes-Festen DAM. Comparison of sleep-wake rhythms in older
adults with intellectual disabilities and the general population. *Sleep
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ABSTRACT

Background Sleep problems are common in people with intellectual disabilities (ID), but the knowledge on the natural course of sleep-wake rhythms and sleep problems in older adults with ID is limited. In the current study, objectively measured sleep-wake rhythms and the prevalence and severity of sleep problems of older adults with ID was compared to that of healthy older adults from a large representative sample from the general population.

Methods Actigraphy data of 501 older adults with ID (age 62.02 ± 8.02 years, 48% female) from the Healthy Ageing and Intellectual Disabilities study was compared to the data of 1734 older adults from the general population (age 62.24 ± 9.34 years, 53% female) from the Rotterdam Study. Main outcome variables were Interdaily stability (IS) and Intradaily variability (IV), total sleep time (TST), Waking after sleep onset (WASO), Short sleep (TST < 6 hours), Night waking (WASO > 90 minutes).

Results Older adults with ID had less stable sleep wake rhythms than older adults from the general population (IS = $.70 \pm .17$, versus $.80 \pm .10$ $z = -8.00$). Their sleep-wake rhythm was also more fragmented (IV = $.56 \pm .26$ versus $.42 \pm .13$ respectively, $z = 8.00$). Older adults with ID slept on average 60.09 minutes longer than older adults from the general population, and lay awake 48.28 minutes longer after sleep onset. Short sleep in older adults with ID was less prevalent (20.7% vs 30.2%) but more severe (TST in Short sleep; 5.13 ± 0.80 hours versus 5.39 ± 0.50 hours, $z = -2.76$) than in older adults from the general population. Night waking was more prevalent (63.0% vs 17.7%) and more severe in older adults with ID (WASO in Night waking; 150.39 ± 54.72 minutes versus 111.60 ± 17.95 minutes, $z = 7.06$).

Conclusion The differences in sleep-wake rhythms, prevalence and severity of sleep problems between older adults with and without ID are marked and possibly explained by medical, psychiatric conditions and lifestyle in older adults with ID. Better understanding of sleep in older adults with ID is needed to improve the quality of sleep in this population and to diminish health problems related to a disruption of sleep.

INTRODUCTION

Sleep problems are common in people with intellectual disabilities (ID)¹. These sleep problems include a long sleep latency, low sleep efficiency, night waking, and early waking^{1,2}. These problems are typically present from childhood, and are considered to be persistent through adulthood^{2,3}. However, little is known about the natural course of the sleep-wake rhythms and sleep problems at older age, as studies in older adults with ID are scarce^{4,5}.

The only study on the sleep-wake rhythms of older adults with ID, the Healthy Ageing and Intellectual Disabilities study (HA-ID study), showed that the sleep-wake rhythms of 501 older adults with ID were less stable and more fragmented⁶ when compared to a small sample of older adults from the general population (n=50). Sleep is characterized by long time in bed, long night waking and a low sleep efficiency⁷. Seventy-two percent of older adults with ID presented with at least one sleep problem, of which the most common was night waking for more than 90 minutes, with a prevalence of 63.1%⁷. It is unclear how these sleep estimates and sleep problems in older adults with ID differ from those seen in older adults from the general population.

In the general population the sleep-wake rhythms change with age. The sleep-wake rhythms become more fragmented⁸, there is a tendency for earlier bed- and wake times, and the total sleep time shortens with age⁹. These changes in sleep-wake rhythms are the result of the age-related changes in the biological clock in the brain¹⁰⁻¹², that regulates the sleep-wake rhythms¹³. Aside from the age-related changes, sleep-wake rhythms in older adults can be disrupted as a result of medical and psychiatric comorbidities, like chronic pain, cardiovascular disease, depression and anxiety, and medication use¹⁴. In addition, one's lifestyle is also associated with the sleep-wake rhythms and sleep characteristics^{8,14}.

In older adults with ID, multiple comorbidities and use of medication that influence sleep, as well as polypharmacy are more prevalent than in the general population¹⁵⁻¹⁸. In addition, an inactive lifestyle, living in a care facility and being dependent from care givers might also affect the sleep-wake rhythms in this population^{6,7}. All these factors make older adults with ID more vulnerable for disruptions of sleep, in addition to the age-related changes seen in older adults from the general population. Insight in the specific sleep-wake rhythms and sleep problems in older adults with ID is a starting point in improving diagnosis and treatment of the specific sleep problems in this population.

The aims of this study are; 1) to compare sleep-wake rhythms of older adults with ID with that seen in older adults from the general population, and 2) to

compare the prevalence and severity of sleep problems in older adults with ID and those in older adults from the general population.

METHODS

Participants

Older adults with intellectual disabilities

Data on older adults with ID was obtained from the large cohort study ‘Healthy Ageing and Intellectual Disabilities’(HA-ID) in the Netherlands, from which we used the cross-sectional baseline data. The HA-ID study is a collaboration between three care providers for people with ID in the Netherlands (Abrona, Amarant and Ipse de Bruggen) and the research group of Intellectual Disability Medicine at the Erasmus MC, University Medical Center Rotterdam. All older adults of 50 years and older (n=2322) who received care from the collaborating care providers were invited to participate in the HA-ID study. A total of 1050 older adults were included in the study. Most of the participants of the HA-ID study (94.2%) resided in a group home for people with ID where they receive care and/or support. An extensive description of the design, recruitment and measurements has been presented elsewhere¹⁹. The Medical Ethical Committee of the Erasmus MC provided ethical approval of the study (MEC 2008-234). Written informed consent was obtained from all participants or their legal representatives. Participants who would refuse to wear the measurement instruments, or were known to easily lose or break the measurement instruments were excluded from this study. Data on sleep-wake rhythms and sleep was collected between February 2009 and July 2010. Data of a total of 501 participants was available for the current study.

Older adults from the general population

Data on older adults from the general population was obtained from the Rotterdam Study, a population-based cohort study of older adults (>45 years) which started in 1990 in the district of Ommoord, Rotterdam, the Netherlands. A complete description of the design of the Rotterdam Study is presented elsewhere²⁰. The Rotterdam Study has been approved by the Medical Ethics Committee of the Erasmus MC (registration number MEC 02.1015) and by the Dutch Ministry of Health, Welfare and Sport (Population Screening Act WBO, license number 1071272-159521-PG). Written informed consent was obtained from all participants. Data on rhythms and sleep was collected from December 2004 to April 2007. Participants had to be able to understand the instructions, participants

with considerable cognitive impairment (Mini-Mental State Examination, score < 22)²¹ were excluded from participation in the actigraphy study. A total of 2.632 participants were invited to participate, of whom 2.063 agreed. Data of a total of 1734 participants was available for the current study.

Measurements

Assessment of the sleep-wake rhythms

Both the HA-ID study and the Rotterdam Study used actigraphy, with the Actiwatch, to measure the sleep-wake rhythms and sleep. The Actiwatch is a wrist-worn accelerometer measuring movement activity by means of a piezoelectric accelerometer. The participants of the HA-ID study wore the Actiwatch 7 (Cambridge Technology Ltd, Cambridge, United Kingdom), participants from the Rotterdam study wore the Actiwatch 4 (Cambridge Technology Ltd, Cambridge, United Kingdom). The update between the two models did not affect the accelerometer and therefore the models are comparable. The Actiwatch is considered a valid and reliable measurement of the sleep-wake rhythms and sleep in adults from the general population²² and in older adults with ID²³.

In the HA-ID study activity counts were set to sum activity counts for 1-min epochs, whereas the Rotterdam Study used epochs of 30 seconds. Each study accounted for the epoch length when converting the raw data to the final outcome variables. Thus the different epoch lengths between the studies did not affect the comparability of the outcome variables. Both studies used the high sensitivity setting (20 counts per epoch), as this showed to be the most sensitive to detect wake^{23,24}.

Participants of the HA-ID study wore the Actiwatch for 14 consecutive days on the non-dominant wrist. A measurement was considered valid if it provided at least 7 days of usable data. In the Rotterdam Study, participants wore the Actiwatch for 7 consecutive days and data was considered valid if it consisted of at least 4 days of usable data. The participants of the HA-ID study provided on average 12.98 days (SD = 1.67 days) of usable data, and the participants of the Rotterdam Study 5.75 days (SD = .58 days). This difference is not considered relevant for the comparison of sleep estimates, as in older adults the means for sleep estimates have previously been found to remain consistent over using 3, 7 and 14 days of data in the general population²⁵.

Based on the distribution of movement activity, sleep-wake rhythms parameters were calculated using non parametric rhythm analyses²⁶. This analysis makes it possible to analyse the rhythms without assumptions on the distribution of the rhythms. The parameters of the rhythms of interest were interdaily stability (IS) and intradaily variability (IV). IS represents the stability of the sleep-wake

rhythms. It ranges from 0 to 1 where 1 represents a perfect stable rhythm over the days. IV indicates the fragmentation of the rhythms. IV ranges between 0 and 2, where a higher score represents a more fragmented rhythm. The Relative Amplitude (RA) is calculated as the difference between the activity per hour of 10 most active hours (M10) and the 5 least active hours (L5) using the formula $RA = M10 - L5 / M10 + L5$. High RA values result from greater daytime activity or reduced activity during sleep. RA scores range from 0 to 1, with higher values indicating a rhythm with higher amplitude.

The Actiwatch software provides the sleep estimates total sleep time (TST, time asleep between sleep onset and final wake time) and waking after sleep onset (WASO, minutes awake between sleep onset and final wake time), an indicator of sleep quality. Based on the TST and WASO, the prevalence and severity of the sleep problems were estimated. Night waking was considered present at $WASO > 90 \text{ min}$ ^{27,28}. A TST of $< 6 \text{ h}$ was considered short sleep^{7,29,30}.

Assessment of demographics, health indicators and lifestyle

Selection of covariates was based on the previous work using actigraphy data in the Rotterdam Study and the HA-ID study⁶⁻⁸. Whenever the measurement of a covariate differed too much between studies, the covariate was excluded from the analysis. This was the case for anxiety and dementia; the HA-ID study screened for anxiety symptoms, whereas the Rotterdam Study diagnosed clinical anxiety disorders. The HA-ID study provided information on the prevalence of dementia, whereas the Rotterdam Study excluded people with dementia from participating in the actigraphy study. The final selected covariates were; age, sex, body mass index (BMI), smoking, ability to perform activities of daily living (ADL), scheduled daily activities and depressive symptoms.

In the HA-ID study, information on age and sex was extracted from the medical records. Body mass index (BMI) was calculated based on the measured height and weight (kg/m^2) of the participants. Information on current smoking (yes/no), ADL and scheduled daily activities was provided by the professional caregiver. The ability to perform basic ADL was assessed with the Barthel Index³¹ that the professional caregiver filled out. Participants who took part in organized daily activities on a regular basis, scored yes on scheduled daily activities (yes/no).

Participants of the HA-ID study were screened for depressive symptoms using two screening instruments³². For participants capable of self-report, the Inventory of Depressive Symptomatology Self Report (IDS-SR) was used, with a cut-off score of 18 for depressive symptoms³³. The Dutch Signaling Depression List for people with Intellectual Disabilities (SDL-ID) was used for participants with insufficient cognitive or verbal capacities to complete self-report³⁴, the cut-off

score of 35 defined participants with clinically relevant depressive symptoms³⁵. If a participant scored above the cut-off on one of these instruments, the participant was classified as having depressive symptoms (yes/no).

In the Rotterdam-study, participants were visited for a home interview during which sex, age, current smoking (yes/no) and scheduled daily activities (yes/no) was assessed. Participants received a yes if they were employed. The ability to perform ADL score was assessed using the Stanford Health Assessment Questionnaire³⁶. Depressive symptoms (yes/no) were assessed with the Center for Epidemiologic Studies Depression (CES-D)³⁷, with a cut-off score of 16 to define clinically relevant depressive symptoms³⁸.

For the purpose of describing the study populations, medication use was extracted from the medical files of the participants in both studies and by cabinet check in the Rotterdam Study. Medications known to or suspected to affect the sleep-wake rhythms or sleep were: antiepileptics (yes/no), psycholeptics (yes/no) and psychoanaleptics (yes/no). In order to describe the study sample of the HA-ID study, level of ID was included in the dataset. Level of ID was obtained from behavioural therapists' records, and was classified as borderline (IQ 70–85), mild (IQ 55–70), moderate (IQ 35–55), severe (IQ 25–35) or profound (IQ <25).

Statistical analyses

Prior to analysis, ADL scores and level of ID were transformed. Because the studies used different instruments for the ADL score, the scores were transformed to percentages ranging between 0 and 100, in which a lower percentage indicating a better ability to perform ADL. Level of ID was described for the participants of the HA-ID study, participants of the Rotterdam Study were categorized as “no ID”.

In order to handle outliers, sleep-wake rhythm- and sleep parameters were winsorized at 3 standard deviations from the mean. Missing data on covariates (ADL; 12.9 % missing data; all other covariates < 5% missing data) were imputed using 5-fold multiple imputation, based on group, covariates and outcome variables.

First, the demographics, health indicators and lifestyle were analysed for possible differences between the two groups, and between HA-ID participants who provided both sleep-wake rhythms and sleep estimates and HA-ID participants who provided only data on sleep-wake rhythms. Continuous variables were analysed using t-test, categorical variables with chi-square test.

We assessed the possible group differences in IS, IV, RA, L5, M10, TST and WASO using linear regression analyses. In the first step the variable group (Rotterdam Study: 0; HA-ID; 1) was added, in the second step we corrected for sex,

age, daily activities, ADL score, BMI, current smoking, and depressive symptoms. The explained variance and confidence interval for the variable group is presented. The group differences for prevalence of sleep problems was assessed in a logistic regression analysis correcting for the same covariates. To study the severity of sleep problems between the two populations, linear regression analyses for TST and WASO was conducted in participants with night waking or short sleep.

Analyses were performed using SPSS statistics (version 25).

RESULTS

Participant characteristics

The dataset of the HA-ID study consisted of 501 participants with actigraphy data, of which 300 participants also provided data for the comparison on the sleep variables. The dataset of the Rotterdam Study consisted of 1734 participants with actigraphy data for the sleep-wake rhythm analysis, of which data of 1728 participants was also available for the comparison of sleep estimates.

Table 1 describes the characteristics of the older adults with ID and older adults from the general population. Older adults with ID and older adults from the general population did not differ in age, sex, BMI and current smoking status. The majority of participants with an ID (84 %) had a borderline to moderate intellectual disability. Participants with ID scored more often above cut off for depressive symptoms (15% vs 9%), were more dependent in ADL (27.3 vs 11.2), participated more often in scheduled daily activities (92% vs. 33%), and used antileptics (18% vs 1%), psycholeptics (29% vs 11%), psychoanaleptics (10% vs 6%) more often than older adults from the general population.

HA-ID participants who provided only data on sleep-wake rhythms (n = 201), were more independent (ADL scores; 23.4 vs 29.9), scored less often above cut off for depressive symptoms (10% vs 18%), used less often anitepileptics (12% vs 22%), and smoked more often (28% vs 20%) when compared to HA-ID participants who provided both data on sleep-wake rhythms and sleep-estimates (n=300).

Sleep-wake rhythms

Table 2 describes the IS, IV, RA, M10 and L5 of older adults with ID and older adults from the general population and the group comparison. The fully adjusted model showed the sleep-wake rhythms of older adults with ID to be significantly less stable (IS: $\beta = -.20$, $p < .001$) and more fragmented (IV: $\beta = .19$, $p < .001$) than

Table 1. Demographics, health indicators and lifestyle characteristics of older adults with ID and older adults from the general population.

	Older adults with intellectual disabilities <i>n</i> = 501	Older adults from general population <i>n</i> = 1734	<i>p</i> - value ^a
<i>Demographics</i>			
Female, (count, %)	249 (48%)	926 (53%)	.16
Age, years (mean, sd)	62.02 (8.02)	62.24 (9.34)	.62
Level of Intellectual disability, (count, %)			
borderline	25 (5%)		
mild	127 (25%)		
moderate	266 (53%)		
severe	48 (10%)		
profound	26 (5%)		
<i>Health indicators</i>			
ADL score, (mean, sd)	27.27 (26.94)	11.20 (16.40)	< .001*
Depressive symptoms, (count, %)	73 (15%)	153 (9%)	< .001*
Use of Antiepileptics, (count, %)	90 (18%)	25 (1%)	< .001*
Use of Psycholeptics, (count, %)	147 (29%)	184 (11%)	< .001*
Use of Psychoanaleptics, (count, %)	50 (10%)	108 (6%)	.01*
<i>Lifestyle</i>			
BMI, (mean, sd)	27.73 (5.20)	27.86 (4.16)	.58
Current smoking, (count, %)	116 (23%)	362 (21%)	.27
Scheduled daily activities, (count, %)	460 (92%)	574 (33%)	< .001*

**p* < .05^a T-test for continues variables, chi-square for categorical variables,

Abbreviation: SD, standard deviation.

that of older adults from the general population. Also, older adults with ID were significantly less active during the day (M10: $\beta = -.24$, $p < .001$) and more active during the night (L5: $\beta = .12$, $p < .001$), resulting in a lower relative amplitude (RA: $\beta = -.17$, $p < .001$) when compared to older adults from the general population.

Sleep characteristics

Table 2 describes the sleep characteristics of older adults with ID and older adults from the general population and the group comparison. In the fully adjusted model, older adults with ID slept on average 60.09 minutes longer than older adults from the general population (TST: 7.4h vs 6.39h, $p < .001$), and lay awake 48.3 minutes longer after sleep onset (WASO: 118.59 minutes vs 69.36 minutes, $p < .001$).

Table 2. Descriptives of sleep-wake rhythms, sleep estimates and sleep problems of older adults with ID and older adults from the general population included in the multivariate regression analyses and test-results for group.

	Older adults with ID		Older adults from general population		Test results for Older adults with ID					
	N	Mean (sd)	N	Mean (sd)	Beta	Standard Error of Beta	Standardized Beta	p-value ^a	R ²	CI
<i>Sleep-wake rhythms</i>										
IS, (mean, sd)	N = 501	.70 (0.17)	N = 1734	0.80 (.10)	-0.08	0.01	-0.20	<.001*	.03	[-0.10, -0.07]
IV, (mean, sd)		0.56 (0.26)		0.42 (0.13)	0.08	0.01	.19	<.001*	.02	[0.06,-0.10]
RA, (mean, sd)		0.64 (0.15)		0.71 (0.10)	-0.05	0.01	-0.17	<.001*	.01	[-0.06, -0.03]
L5, (mean, sd)		11.24 (6.20)		9.24 (4.07)	1.38	0.30	.12	<.001*	.01	[0.80, 1.97]
M10, (mean, sd)		49.28 (10.07)		53.99 (3.71)	-3.532	0.36	-.24	<.001*	.04	[-4.24, -2.82]
<i>Sleep</i>										
TST, hours (mean, sd)	N = 300	7.40 (1.70)	N=1728	6.39 (0.84)	60.09 min	4.55	.34	<.001*	.07	[51.16, 69.02]
WASO, minutes (mean, sd)		118.59 (61.39)		69.36 (25.34)	48.28 min	2.57	.48	<.001*	.14	[43.25, 53.32]
<i>Sleep problems</i>										
Short sleep (TST<6h), %	N = 300	20.7	N = 1728	30.2	Beta	Standard Error of Beta	Exp (b)	p-value ^b	Nagelkerke R ²	CI Exp(b)
Night waking (WASO>90 min), %		63.0		17.7	-0.78	0.18	0.46	<.001*	.09	[0.32, 0.66]
at least 1 sleep problem, %		67.3		38.8	2.13	0.18	8.39	<.001*	.19	[6.28, 14.79]
<i>Sleep problems in older adults with ID</i>										
TST in hours in short sleep (mean, sd)	N = 62	5.13 (0.80)	N = 523	5.39 (0.50)	Beta	Standard Error of Beta	Standardized Beta	p-value ^a	R ²	CI
WASO in minutes in night waking (mean, sd)	N = 189	150.39 (54.72)	N = 306	111.60 (17.95)	-14.10	5.10	-.09	.006*	.01	[-24.14, -4.06]
					35.94	5.09	.37	<.001*	.08	[25.95, 45.93]

Table 2. Legend* $p < .05$

^amultivariate linear regression analyses mutually adjusted for group, sex, age, daily activities, ADL score, BMI, current smoking (yes/no), depressive symptoms (yes/no). Older adults from general population are reference.

^blogistic regression analyses mutually adjusted for group, sex, age, daily activities, ADL score, BMI, current smoking (yes/no) and depressive symptoms (yes/no). Older adults from general population are reference.

Abbreviations: ADL, ability to perform activities of daily living score; BMI, body mass index (Weight (kg) height (m)²); CI, 95% confidence interval; M10, 10 hour period of most activity during day; L5, 5 hour period of least activity during the day, ID, intellectual disabilities; IS, interdaily stability; IV, intradaily variability; RA, relative amplitude; SD, standard deviation; TST, total sleep time; WASO, waking after sleep onset.

Short sleep (TST < 6h) was more prevalent in older adults from the general population compared to older adults with ID (30.2% vs 20.7% respectively). In older adults with ID with short sleep, short sleep was more severe when compared to short sleep in older adults from the general population as shown by the TST being 14 minutes shorter ($p < .006$). Night waking (WASO > 90min) was more prevalent in older adults with ID (66.3% vs 38.4%, OR 8.39, $p < .001$). Night waking was more severe in older adults with ID with night waking as shown by the WASO being 36 minutes longer ($p < .001$), when compared to older adults from the general population with night waking. For older adults with ID, the chance of having at least one sleep problem was a 2.5-fold higher than for older adults from the general population having at least one sleep problem. Correcting for covariates did not change these results.

DISCUSSION

In the current study, we compared objectively measured sleep-wake rhythms and sleep of older adults with ID with that of a representative sample of older adults from the general population. We found that the sleep-wake rhythms of older adults with ID were more fragmented and less stable than that of older adults in the general population. Older adults with ID sleep longer, but have more trouble maintaining sleep as resembled by the higher prevalence of people experiencing night waking. Sleep problems seem to be more severe in older adults with ID. When corrected for demographics, mental health indicators and lifestyle characteristics, the differences in sleep-wake rhythms between the two groups remained. The results of our study show that the sleep-wake rhythms and sleep characteristics seen in older adults with ID are not solely the result of aging as is seen in the general population.

The population of older adults with ID who receive organized care is best described by a distinctive combination of characteristics that might all together

affect their sleep-wake rhythms and sleep. The intellectual disability itself might seem an obvious factor, though the mechanism of ID on the sleep-wake rhythms is largely unknown. Syndromes associated with ID like Down syndrome, Smith-Magenis and Angelman syndrome, are known for their atypical sleep-wake rhythms and high prevalence of sleep problems³⁹⁻⁴¹. In addition, health conditions like diabetes, epilepsy and psychopathology are common in older adults with ID¹⁵ and are associated with sleep problems⁷. The medications commonly used in these conditions, for instance antidepressants, antiepileptics and antipsychotics, also impact the sleep-wake rhythms^{1,6,7}.

The care dependency is another feature that distinguishes older adults with ID from older adults from the general population. All participants with ID in our study sample received organized care and 95.3% lived in a care facility. The daily schedule of care in group homes entails nearly all facets of the life of the resident; from dressing, eating and from being assisted around bedtime to activities during the day. In nursing home residents as well as in older adults with ID, care dependency is shown to affect the sleep by lowering the subjective sleep duration and increasing the time spend in bed^{7,42}.

This care dependency might explain the longer total sleep duration in older adults with ID when compared to that of older adults from the general population. These care schedules are pragmatic but do not account for the personal preference of the residents. Nor is the schedule adjusted to the experienced sleep pressure, or tiredness, of the resident. Based on the ADL item “transfer from/to bed”, 20% of our sample of older adults with ID receives verbal or physical assistance by professional caregivers with getting in and out of bed. This might lead to longer time in bed, and more opportunity for sleep thus resulting in longer total sleep time, but also more opportunity to lay awake.

The effect of care dependency is not limited to sleep alone; older adults with ID depend on third parties like care professionals to undertake all sorts of activities during the day, such as walking and crafts. These activities induce the accumulation of sleep pressure, or sleepiness, needed for falling asleep and maintaining sleep⁴³. Older adults with ID are known to be little physically active and show high levels of sedentary behaviour^{44,45}. Sedentary behaviour is in turn related to insomnia and sleep problems⁴⁶, whereas more activity was related to higher stability and less fragmentation of the sleep-wake rhythms in older adults with ID⁶.

The impact of sleep disturbances seen in older adults with ID is illustrated by the poor sleep quality, as indexed by the long WASO in our sample. The WASO is on average 47 minutes longer in older adults with ID than in older adults from the general population. Another indicator of sleep quality is sleep efficiency, the

percentage of time in bed spend sleeping. Based on the TST and WASO, people with ID spend at least 10 hours in bed, compared to 7 hours in older adults without ID. This results in a sleep efficiency of at most 78% for people with ID, compared to 86% in older adults from the general population, whereas an efficiency of minimal 80% is considered adequate. Thus, longer sleep duration does not automatically translate to a good sleep quality in older adults with ID.

In addition, although we did not measure all facets of sleep we consider the night waking as excessively long. When night waking is assessed in the context of insomnia, a cut-off for WASO of 30 to 66 minutes is applied^{47,48}. In our sample, older adults with ID lie awake 24 minutes more. For diagnosing insomnia, the duration, frequency and the subjective experience of complaints are required. Due to the cognitive or communicative limitations, reporting a subjective experience in older adults with ID is challenging. Therefore, objective criteria to diagnose insomnia in people with ID are explored⁴⁹. Nevertheless, our findings of very substantial unrecognized sleep problems in this population is highly relevant.

Strengths and Limitations

The current study is the first to compare actigraphy data of older adults with ID with a representative sample of older adults from the general population. The sleep-wake rhythms and sleep were measured with valid and reliable measurements for measuring sleep. The findings must be generalized with caution as the study sample is almost representative of all older adults with ID receiving care in the Netherlands¹⁹.

The two study populations were not assessed for a comparative study. This resulted in a lack of overlapping covariates between the two studies. As a result, we were not able to fully correct for comorbidities (e.g. neurodegenerative disorders like dementia) and medication use that might influence sleep. The Actiwatch is considered a valid and reliable measure of sleep, but it is less capable to measure waking accurately (van de Wouw et al., 2013a). Older adults with ID specifically have a tendency to be awake, while lying still in bed. Consequently, the TST might be overestimated, and the WASO might have been underestimated in this study. The current study addressed at a limited number of sleep outcomes; TST and WASO. Additionally, sleep onset latency and sleep efficiency are important sleep characteristics. Sleep onset latency was defined differently in both studies, which made a comparison less reliable. Nonetheless, our findings might be an underestimation of the sleep-wake rhythms and sleep problems seen in older adults with ID.

Future research and clinical relevance

Future research on sleep in people with ID should focus on describing the sleep-wake rhythms and sleep and the development with age in adults with ID using objective and well validated measurements like actigraphy and polysomnography. Secondly, identifying objective cut-off scores and definitions for sleep-wake rhythms and sleep problems in older adults with ID are required and can be of great benefit in diagnosing sleep problems in this population.

The findings of the current study indicate the need for more attention on sleep problems in older adults with ID. Improving the sleep quality by bedtime scheduling and educating caregivers was found to be effective⁵⁰, but availability of evidence based interventions for sleep problems in adults and older adults with ID are limited^{51,52}. Scheduling bedtimes based on the preference and sleep-wake rhythms of the individual residents, instead of the work schedule of the professional care givers could be a starting point.

Conclusion

We found that the sleep-wake rhythms of older adults with ID are more fragmented and less stable when compared to that of older adults in the general population. Even though older adults with ID sleep longer, they have more trouble maintaining sleep as resembled by a higher prevalence of people experiencing night waking. We conclude that the characteristics of sleep-wake rhythms and sleep in older adults with ID who receive organized care are not merely the result of aging as seen in older adults from the general population. The results suggest that the combination of ID, comorbidities, medication use and care dependency might explain the characteristics. The sleep quality in older adults with ID is low and might be a precursor for underlying sleep problems. A better understanding of sleep and clear definitions of sleep problems in adults, and specifically older adults, with ID is needed. These serve as a starting point to improve the quality of sleep in this population and to diminish health problems related to a disruption of sleep.

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3

Are we still in the dark?

A systematic review on personal daily light exposure, sleep-wake rhythm, and mood in healthy adults from the general population

Mylène N. Böhmer , Pauline C.M. Hamers,
Patrick J.E. Bindels , Alyt Oppewal, Eus J.W. van Someren,
Dederieke A.M. Maes-Festen

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ABSTRACT

Background Insufficient light exposure is assumed to be related to a wide array of health problems, though few studies focus on the role of whole-day light exposure in the habitual setting in the development of these health problems. The current review aims to describe the association between personal light exposure in the habitual setting and sleep-wake rhythm and mood in healthy adults from the general population.

Methods Five databases (Embase, Medline Epub, Web of Science, PsycINFO, and Google scholar) were searched in June 2019. The inclusion criteria included: assessment directly of light exposure on the participants for at least one full day; reporting on both individual personal light exposure and outcomes. The quality of the papers was assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies of the National Heart, Lung and Blood Institute. The current review followed the PRISMA guidelines.

Results In total, 8140 papers were identified in the database search. Twenty-five papers were eventually included in this review. All included studies were cross-sectional, and individual light exposure was usually measured with a wrist-worn device. Five studies received a “good” quality rating, 16 received a “fair” rating, and the remaining four a “poor” quality rating. The overall quality of the included studies was considered low because of the lack of intervention studies and the fact that light exposure was measured on the wrist.

Conclusion Given the low quality of the included studies, the current review can only provide a first exploration on the association between light exposure and sleep-wake rhythm and mood in healthy adults from the general population. Limited evidence is presented for a positive relationship between the amount and timing of light exposure on the one hand and rest-activity rhythm and some estimates of sleep architecture on the other. The evidence on an association between light exposure and circadian phase, sleep estimates, sleep quality, and mood is conflicting. Data from intervention studies are needed to gain insight into the causal mechanism of the relationship between light exposure and sleep-wake rhythm and mood.

INTRODUCTION

Light is as important for perceiving the world as it is for regulating physiological and behavioral rhythms. These follow a circadian rhythm, a rhythm of approximately 24 hours. Circadian rhythms are regulated by the biological clock, which is located in the suprachiasmatic nucleus in the hypothalamus. Circadian rhythms synchronize to the external 24h rhythm using external cues called “Zeitgebers,” of which light is the strongest ¹.

Alignment of the circadian clock with external day-night rhythm is considered essential for the regulation of the sleep-wake rhythm and mood ^{2,4}. Insufficient, or badly timed, exposure to light can ultimately result in desynchronization of the sleep-wake rhythm and sleep problems, which in turn can result in mood problems ³. Misalignment of circadian rhythms ^{2,5} and disturbances of the sleep-wake rhythm ⁶ and mood ⁷ are each associated with poor health outcomes.

Research in populations exposed to light patterns that are extremely deviated from the natural dark-light cycle (e.g. shiftwork, jetlag, and a late chronotype) has provided knowledge on the relationship between light exposure, sleep-wake rhythm mood, and other health complaints. For instance, traveling through time zones has been associated with disruption of the circadian rhythm ⁸, whereas shiftwork is associated with sleep problems and lower sleep quality ⁹, depressed mood ^{10,11}, cardiovascular diseases, gastro-intestinal and metabolic disorders, ¹² as well as cancer ¹³⁻¹⁵. The exposure to extremely deviating light patterns is assumed to play a role in the development of these health problems ¹¹.

To date, evidence on the relationship between light, sleep-wake rhythm and mood is provided by both fundamental studies in humans and studies in populations with extreme deviating light exposure patterns. For the general population in everyday living conditions this relationship is less clear. Associations between light exposure and health in populations prone to extreme deviating light patterns are not necessarily generalizable to the general population. Although not as extremely deviating, the general population might be exposed to suboptimal light as well; for instance due to little bright light exposure ¹⁶⁻¹⁸, poorly lit homes and workspaces ¹⁸⁻²⁰, or evening light exposure using multimedia devices ²¹. So far, we are lacking an overview of the evidence on the relationship between daily light exposure in the habitual setting and sleep-wake rhythm, and mood in the general population.

The aim of the current systematic literature review is to provide an overview of the literature on the association of personal light exposure in the everyday (habitual) setting, with sleep-wake rhythm, and mood in healthy adults from the general population. The current review will focus on personal light exposure

as measured directly on the participants, as this is considered more reliable than a proxy such as light exposure measurements in the environment²². No restrictions will be made with regard to the features of light exposure; the timing, amount, and spectral distribution will all be described. Also, the outcomes in terms of sleep-wake rhythm and mood will be explored broadly and without restrictions. This way, we aim to determine the potential impact of personal daily light exposure on sleep-wake rhythm and mood.

METHODS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines²³ were followed during this review. This review was registered in the Prospero register under number CRD42016039107.

Search Strategy

The search was performed within multiple electronic databases in order to reduce the risk of missing eligible articles. Embase, Medline, Psycinfo, Web of Science, and Google Scholar were searched on June 14, 2019. The database-specific search codes used are shown in the Appendix. In addition, the reference lists in the included papers were examined for further relevant papers.

Definitions and Inclusion Criteria

The aim of the review is to study the association of personal light exposure in the habitual setting during the day with sleep-wake rhythm and mood in the general population. Personal light exposure refers to the light exposure measured on the participant directly as this is considered more reliable than indirect measurements of light exposure such as light measurements in the environment²². Light exposure could be both artificial light and sunlight. All features of light exposure were included; the timing, amount, and spectral distribution will all be described. The habitual setting is defined to include all real-life settings. Studies conducted in a laboratory or experimental setting were excluded. Real-life intervention studies that included baseline analyses of the association between light exposure and outcomes were included. With regard to the population, we aimed for healthy adults from the general population who were not likely to be exposed to extreme deviating light exposure patterns, therefore excluding shift workers, studies of chronotypes, and jetlag. No criteria were formulated for the outcome variables of sleep-wake rhythm, thus 24 hour activity-rest rhythm, sleep estimates or sleep problems could all be included. "Mood" was used as an

umbrella term to capture all possible facets of the term; both states and traits (affect vs. temperament) could be included, as well as mood complaints.

Studies had to meet the following inclusion criteria: published in the English language, study sample of healthy adults aged ≥ 18 from the general population; light exposure was measured directly on the participant for at least one full waking day; the study took place in a habitual setting; sleep-wake rhythm and/or mood, and analyses of the relationship between habitual daily light exposure and sleep-wake rhythm and/or mood were reported.

Studies were excluded if participants were likely to have deviating light patterns (shiftwork, jetlag, chronotype), participants had pre-existing sleep- or mood disorders or other known physical or mental conditions, if the full text was not available through the medical libraries or if the text was a conference abstract. Studies conducted in the controlled environment of a laboratory were also excluded.

Selection Process

The selection of papers was carried out by the first and second authors. After the electronic database search, the titles and abstracts were screened for eligibility. Then the full text was read of the eligible papers. Disagreement between the two authors was resolved through consensus discussions. The bibliography of selected papers was screened for possible relevant papers that were not included in the electronic database search. These papers were screened in the same manner as papers from the electronic database search (Figure 1).

Data Extraction and Management

In the data collection phase, all results were extracted of analyses of the relationship between light exposure and the outcome measures sleep-wake rhythm and mood.

Quality Assessments

Selected studies were assessed for methodological quality using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies of the National Heart, Lung and Blood Institute²⁴. The Quality Assessment Tool consists of 14 items that can be scored as “yes,” “no,” “not applicable” or “not recorded”. Each “yes” was rewarded with one point; studies could score a maximum of 14 points.

Based on the quality assessment, an overall rating of “poor,” “fair” or “good” was determined. Studies that scored nine points or more received an overall “good” rating; however, if only basic analyses (such as correlations) were per-

formed the study was assigned a “fair” overall rating. Studies with eight points with advanced analysis (such as regression analyses) received a “good” rating. Studies with six to eight points received a “fair” rating, unless they had a small sample size ($N < 30$); those studies were given a “poor” rating. Studies with five points or fewer were all rated as “poor”.

The quality assessment was done by the first author, who assessed all the included studies and determined the overall rating for the quality of the study. Next, the findings were presented to the second author to check whether the quality assessment of all the studies had been performed in a consistent manner. Disagreements were resolved through a consensus discussion.

The current review itself was not assessed on quality, as to date no appropriate tool exists to do a quality assessment of reviews that include merely observational studies.

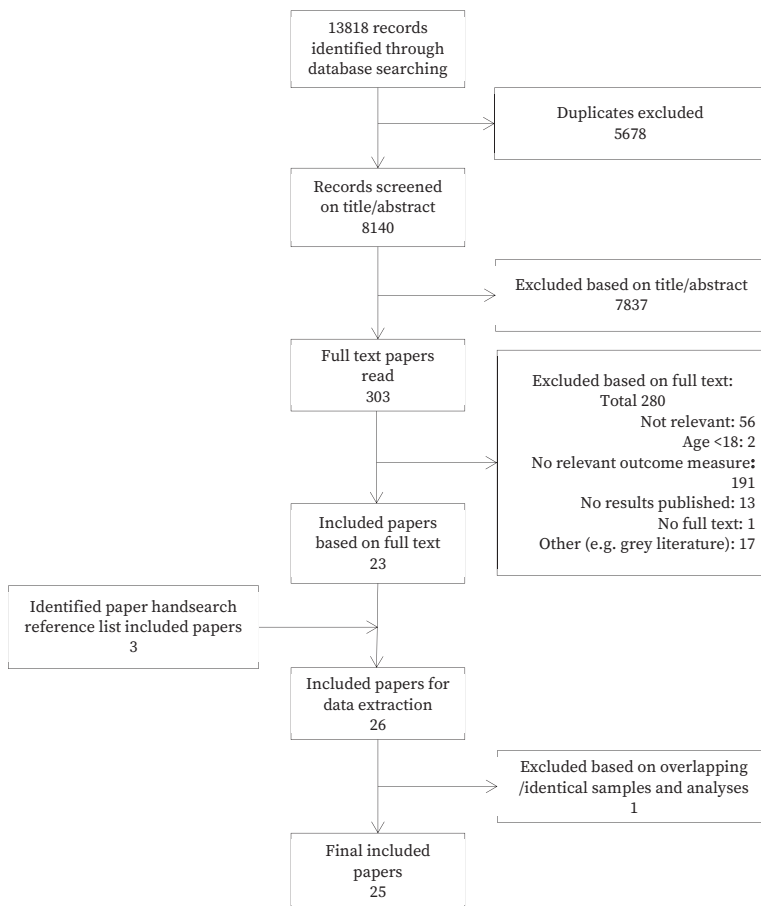


Figure 1. Flowchart of paper selection.

RESULTS

Selection of Studies

The search for studies on the association between daily light exposure and sleep-wake rhythm and mood generated 8140 unique articles (Figure 1). Based on title-abstract screening, 303 were considered eligible. After reading the full text of these articles, 23 articles were included. Most of the excluded studies (n=279) were excluded because they did not report on personal light measurements. After including three articles from the reference lists of the included papers, a total of 26 articles were obtained for data extraction.

With regard to overlapping populations, three papers published results on the same group of post-menopausal women from the Women's Health Initiative²⁵⁻²⁷. In two cases, there were two different papers that reported on the same group of healthy volunteers²⁸⁻³¹. For these studies, only the first unique analysis will be reported. Two studies^{25,32} described identical populations and data analysis relevant for the current review, therefore one of these — the study of Youngstedt et al. (2004)³² — was excluded.

Of the final 25 articles included, ten focused solely on sleep-wake rhythm^{30,33-41}, four on sleep-wake rhythm and mood^{19,25,27,42}, and the remaining 11 studies focused solely on mood^{26,28,29,31,43-49}.

Quality Assessment of the Included Studies

Information needed to rate the items of the Quality Assessment Tool was not always reported in the articles, which restricted the proper assessment of the risk of bias. Five studies received an overall “good” rating^{19,34,36,43,49}. Sixteen studies were rated as “fair”^{25,27-31,33,35,37,39,41,42,44,46-48}. The remaining four studies were rated as “poor”^{26,38,40,45}. No sample size justification was provided for 22 studies, but due to the observational nature of the studies, this was not considered to impact the quality of the studies too much. Twenty studies did not report on the participation rate of eligible persons, which might have resulted in an unrepresentative sample of the target group. Fifteen studies measured the light exposure once or averaged the light exposure over the measurement period, making it not possible to show an effect of changes in light exposure over time, thus resulting in a weaker study design. Fourteen studies measured the light exposure (mostly) at the time of the outcomes rather than prior to the outcomes, which makes it not possible to study a causal relationship between light exposure and the outcomes. Table 1 gives the complete overview of the results of the quality assessment.

Table 1. Quality of the included studies (NIH National Heart, Lung and Blood Institute Study quality assessment tool)

	aan het Rot et al. (2008) ⁴³	Araki et al. (2012) ²⁸	Asai et al. (2018) ⁴⁸	Beale et al. (2017) ⁴¹
1. Was the research question or objective in this paper clearly stated?	yes	yes	yes	yes
2. Was the study population clearly specified and defined?	yes	no	yes	yes
3. Was the participation rate of eligible persons at least 50%?	NR	yes	yes	ND
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study pre-specified and applied uniformly to all participants?	yes	no	yes	ND
5. Was a sample size justification, power description, or variance and effect estimates provided?	no	yes	no	no
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	no	no	NR	no
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	yes	yes	NR	yes
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	yes	no	no	yes
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	yes	yes	yes	yes
10. Was the exposure(s) assessed more than once over time?	yes	no	no	no
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	yes	yes	yes	yes
12. Were the outcome assessors blinded to the exposure status of participants?	NA	no	NA	NA
13. Was loss to follow-up after baseline 20% or less?	no	NA	NA	NA
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	yes	no	yes	no
Additional criteria ^a	AA, SS	BA	BA	BA
Total score	9	6	7	6
Quality rating (poor, fair or good)	good	fair	fair	fair

*ND = not determined, NR = not reported

^a Additional criteria for final quality rating. Abbreviations: AA, advanced analyses; BA, basic analyses; SS, small sample (N<30)

Boubekri et al. (2014) ³⁹	Crowley et al. (2015) ³⁵	Espiritu et al. (1994) ⁴⁴	Figueiro et al. (2016) ⁴⁰	Figueiro et al. (2017) ⁴²	Grandner et al. (2006) ²⁶	Hoaki et al. (2011) ²⁹	Hood et al. (2004) ³⁷	Hubalek et al. (2010) ¹⁹	Itzhacki et al. (2019) ⁴⁹	Jean-Louis et al. (2005) ³⁰	Jean-Louis et al. (2005b) ³¹	Koller et al. (1993) ⁴⁵	Kripke et al. (2004) ²⁵	Martinez-Nicolas et al. (2011) ³⁸	Phillips et al. (2017) ³³	Smolders et al. (2013) ⁴⁶	van der Maren et al. (2018) ³⁴	Wallace-Guy et al. (2002) ²⁷	Wams et al. (2017) ³⁶	Wang et al (2003) ⁴⁷
yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
yes	yes	yes	no	yes	yes	yes	no	yes	no	yes	no	no	yes	yes	yes	no	no	yes	yes	yes
NR	NR	no	NR	NR	ND	yes	NR	NR	NR	NR	NR	NR	ND	ND	NR	ND	NR	no	ND	NR
yes	no	yes	yes	yes	yes	no	NR	yes	yes	no	no	ND	no	NR	yes	no	yes	yes	no	yes
no	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no	no	yes	no	no
NR	no	ND	no	yes	yes	no	no	yes	yes	no	yes	no	yes	no	no	yes	yes	yes	yes	no
yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
yes	yes	yes	no	yes	no	no	yes	yes	yes	no	no	no	no	yes	no	no	yes	no	yes	no
yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes
no	yes	no	yes	yes	no	no	no	yes	yes	no	no	yes	no	no	no	yes	yes	no	yes	no
yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	no	yes	yes	yes	no	yes	yes
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	no	NA
NA	no	NA	no	no	NA	NA	NA	NA	yes	NA	NA	NR	NA	NA	NA	NA	NR	NA	NA	NA
no	no	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	NA	yes	yes	no
BA, SS	BA, SS	BA	AA, SS	BA	BA	BA	BA	BA, SS	AA	BA	BA	AA, SS	BA	BA	BA, SS	AA	AA	BA	SS	AA
7	7	8	6	9	5	7	6	9	10	6	6	5	7	5	7	7	8	8	9	6
fair	fair	fair	poor	fair	poor	fair	fair	good	good	fair	fair	poor	fair	poor	fair	fair	good	fair	good	fair

Note. Question 5: Sample size of n < 30 was considered small. Question 6: studies that measured exposure prior to the outcome received a “yes”; if exposure was measured at the same time as or after the outcome, this question was scored “no”. Question 7: studies received a “yes” if light exposure was measured for at least three days. Studies that scored nine points or more received an overall “good” rating; however if only basic analyses (such as correlations) were performed the study was assigned a “fair” overall rating. Studies with eight points that included advanced analysis (such as regression analyses) received a “good” rating. Studies with six to eight points received a “fair” rating, unless they had a small sample size (N < 30) — those studies were assigned a “poor” rating. Studies with five or less points were all rated as “poor”.

Light Exposure Measurement

Within the 25 studies, 11 different devices were used to measure personal light exposure. Measuring light exposure at eye level is preferred as it is the most reliable way to estimate the amount of light that enters the eye. Three studies measured light exposure at eye level using a device that was attached to glasses that the participants wore^{19,45,46}. In one study, the participants wore a lanyard with a light sensor as a necklace³⁸; in another study the light cell was pinned as a brooch⁴⁹. In 19 studies, participants wore an accelerometer with an integrated light cell on their wrist^{25-31,33-37,39-44,47,48}. New-generation wrist-worn accelerometers, used primarily to measure sleep-wake activity, often come with an integrated light sensor. Although practical, the amount of light exposure measured at wrist-level is less reliable. When compared to eye level, the amount of light exposure measured at wrist level deviates by up to 27%⁵⁰.

All studies measured light at least for one complete waking day of the participants, as this was an inclusion criterion. The duration of the measurements varied between 16 hours and 10 days.

The average intensity of light exposure in lux was reported in 21 studies^{19,25-31,33,34,36,38-43,45-47,49}. Duration of light exposure above a pre-defined threshold in lux was reported in six studies^{19,35,37,44,46,48}. Two studies grouped participants based on low or high light exposure according to quartiles or by a cut-off value of light exposure defined by the authors^{42,43}.

The timing of light exposure was reported in nine studies^{26,27,31,33-36,38,45,46}. These studies reported the average light exposure in the morning or evening, or mentioned the timing of the maximum light exposure (acrophase of the light exposure pattern).

Associations between Light Exposure and Outcomes

Based on the reported light exposure outcome variables, a description will be given of the association between the amount (defined as the average intensity of light exposure in lux, unless specified otherwise), duration, and timing of light exposure on the one hand and the outcome variables sleep-wake rhythm, and mood on the other hand. The results will be described starting with the highest quality study included. In the case of significant results, all the test results and p-values for the light exposure variables reported in the papers are presented in both the text and the tables.

We acknowledge the broadness of our research question, but we are interested in determining the potential impact of personal daily light on sleep-wake rhythm, and mood even if we could not be definitive about the specific conditions and effects. Therefore, in order to qualify the results, the conclusions per

domain are drawn based on an adaptation of the Cochrane classification of the level of evidence ⁵¹:

- Strong evidence — consistent findings among multiple high-quality studies;
- Moderate evidence — consistent findings among multiple fair/low-quality studies and/or one high-quality study;
- Limited evidence — consistent findings among multiple low-quality studies;
- Very limited evidence — single low-quality study;
- Conflicting — inconsistent findings among multiple studies;
- No evidence — no studies available.

Sleep-wake rhythm

Assessment of sleep-wake rhythm

Outcomes for the sleep-wake rhythm are described within the domains sleep-wake rhythm and sleep quality. The 12 studies on light exposure and sleep-wake rhythm and seven studies on light exposure and sleep quality are described in Tables 2 and 3. Of these studies, five studies solely used actigraphy to measure sleep-wake rhythm ^{27,37,39,41,42}. One study used both actigraphy and sleep diaries or questionnaires ²⁵. Four studies focused on measuring melatonin levels or dim light melatonin onset (DLMO) as indicator of the circadian phase of the sleep-wake rhythm ^{30,33-35}. Wams et al. (2017)³⁶ used polysomnography (PSG) in combination with actigraphy and DLMO measurements.

Sleep quality was measured in seven studies, of which four ^{36,39,40,42} used the well-validated Pittsburgh Sleep Quality index (PSQI) ⁵². Two actigraphy studies reported the sleep efficiency as a proxy for sleep quality ^{27,39}. The self-reported PROMIS Sleep disturbance short form for measuring sleep problems in addition to measuring sleep quality was used twice ^{40,42}. The last two studies ^{19,25} added questions on subjective sleep quality to the questionnaires.

Association between light exposure and sleep-wake rhythms and sleep quality

Because of the broad variety of outcome measures for sleep-wake rhythms and sleep quality, results are grouped per outcome measure.

Rest-activity rhythm Light exposure and rest-activity rhythms were studied in one fair-quality study ⁴² and one poor-quality study ³⁸. Exposure to light of high intensities during the day was associated with higher phasor magnitude ($F_{1,39} = 35.38, p < .0001$) ⁴² and stability of the sleep-activity rhythm ($r = .343, p < .01$) ³⁸.

Table 2. Characteristics of included studies that examine the association between personal light exposure and sleep-wake rhythm in the general population.

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Sleep-wake rhythm	Light exposure outcome	Sleep-wake rhythm outcome	Results	RoB*
Beale et al. (2017) ⁴¹	Mozambique	Cross-sectional, volunteer sample N = 74	Adults from an electrified city and an unelectrified rural settlement in the Milange district, Zambézia province, Mozambique. 34.68 years (SD = 8.73) 42% female	ActiTrust (AT0503 Condor Instruments, São Paulo, Brazil)	ActiTrust (AT0503 Condor Instruments, São Paulo, Brazil)	Total light exposure with most illumination Total light exposure in the 3 hours after sunset (light at night)	Sleep onset Nocturnal activity L5 onset (onset of 5 hours of least activity)	Sleep onset is negatively correlated with amount of daytime light exposure ($r = -.41$, $t(60) = -3.49$, $p < 0.001$). More light prior to sleep time resulted in a later sleep onset latency ($r = .61$, $t(60) 5.93$, $p < 0.001$). L5 onset ($r = -.23$, $t(60) = -2.58$, $p = 0.012$) correlated negatively with amount of daytime light exposure. Nocturnal activity was not associated with the amount of evening light when adjusted for age, sex, and location ($R^2 = 0.28$, $\beta_{\text{evening light}} = -5.6 \times 10^{-5}$, $p = 0.77$, $\beta_{\text{hourly}} = 0.25$, $p = 0.00005$).	fair
Boubekri et al. (2014) ³⁹	U.S.A.	Cross-sectional, convenient sample N = 21	Volunteers from office locations with and without windows. Descriptives of this sample not reported, descriptives below are for the full sample of 49 participants. 19-60+ years 61.22 % female	Actiwatch-L (Minimitter)	Actiwatch-L (Minimitter)	Average light exposure	Sleep onset Sleep onset latency Wake after sleep onset Sleep duration Sleep fragmentation	Workers with access to daylight had a longer sleep duration than workers without access to daylight (476.31 minutes versus 429.65 minutes, $p < .05$). There were no significant differences between workers with windows and workers without windows in sleep onset time (21:46 versus 22:04), sleep onset latency (10 min vs 19 min), sleep efficiency (91% vs 89%), wake after sleep onset (30 min vs 37 min), and sleep fragmentation (19 vs 22) on workday nights.	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measure-ment: Light exposure	Measure-ment: Sleep-wake rhythm	Light exposure outcome	Sleep-wake rhythm outcome	Results	RoB*
Crowley et al. (2015) ³⁵	U.S.A.	Cross-sectional, volunteer sample N = 14	Full-time office workers 28 years (SD = 5) 71% female	Actiwatch Spectrum (Philips Respironics Inc. Bend, OR)	Dim Light Melatonin Onset	Total minutes and timing of exposure above 10, 180, 550 and 1000 lux	Dim Light Melatonin Onset (DLMO)	Total duration of light exposure at any level did not correlate with the DLMO. The DLMO was later if the first exposure to 10 lux ($r = 0.55$, $p = 0.04$) and 180 lux ($r = 0.61$, $p = 0.02$) were also later. Trends were seen for the 550 lux ($r = 0.51$, $p = 0.06$) and 1000 lux ($r = 0.52$, $p = 0.06$) thresholds. Similarly, the DLMO was later if the last daily exposure to 180 lux was also later ($r = 0.77$, $p = 0.001$). A similar trend was seen for the 10 lux threshold ($r = 0.49$, $p = 0.08$), but the last daily exposures to 550 lux and 1000 lux were not associated with the DLMO.	fair
Figueiro et al. (2017) ⁴²	U.S.A.	Cross-sectional, volunteer sample N=67	Workers in 5 buildings of the U.S. General Services Administration in Washington DC (2x), Portland OR, Seattle WA, Grand Junction Colorado Age not reported 63% female	The Day-simeter, (Lighting Research Center, Troy, NY)	The Daysimeter, (Lighting Research Center, Troy, NY)	Morning or workday CS; Magnitude of circadian stimulus calculated using light exposure and circadian illuminance (CS) in the morning or workday (high vs low)	Phasor magnitude Phase angle Sleep onset latency Sleep time Wake time Sleep efficiency	Participants who had high workday CS had greater phasor magnitudes than those who had low workday CS ($F_{7,39} = 35.38$, $p < .0001$). Workday CS did not affect the phasor angle. High morning CS was associated with greater phasor magnitudes ($F_{1,46} = 41.94$, $p < .0001$). Morning CS did not relate to phasor angle. Sleep onset latency declined as morning CS increased ($F_{1,62} = 13.49$, $p = .002$). No effect was found for high versus low workday CS and sleep onset latency. No association was found between any of the CS measurements and sleep time, wake time, and sleep efficiency.	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measure-ment: Light exposure	Measure-ment: Sleep-wake rhythm	Light exposure outcome	Sleep-wake rhythm outcome	Results	RoB*
Hood et al. (2004) ³⁷	Australia	Cross-sectional, volunteer sample N = 33	Healthy elderly 74.18 years 66% female	Mini Mitter 2000 Data Logger	Mini Mitter 2000 Data Logger	Light intensity in total minutes above 3,000 lux	Nocturnal immobility	Minutes of light above 3000 lux was positively associated with Nocturnal Immobility data ($R^2 = .519$, $t(26) = 2.408$, $p < .023$).	fair
Jean-Louis et al. (2005b) ³⁰	U.S.A.	Cross-sectional, volunteer sample N = 30	Healthy elderly 69.03 years (SD = 6.84) 80% female	Actiwatch-L (Mini Mitter)	Melatonin	Light exposure acrophase Light exposure mesor	Melatonin acrophase Melatonin mesor	When corrected for sleep and race, light exposure acrophase was associated with a lower melatonin mesor ($r = -.43$, $p = .03$), light exposure mesor was not associated with the melatonin mesor. Light exposure mesor and acrophase were not associated with melatonin acrophase.	fair
Kripke et al. (2004) ²⁵	U.S.A.	Cross-sectional, convenient sample N = 416-450	Menopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume, Ambulatory Monitoring Inc., Ardsley, NY	Actilume, Ambulatory Monitoring Inc., Ardsley, NY Sleep diary	Mesor Log Lux	Objective sleep duration Subjective sleep duration Daytime sleep Sleep acrophase	There was a negative correlation between objective sleep duration and mesor Log lux ($r_f = -.20$, $p < 0.001$). Mesor log lux was not related to subjective sleep duration and daytime sleep. When corrected for age and ethnicity, Mesor Log Lux was positively associated with acrophase of sleep ($r_f = -.14$, $p < 0.005$).	fair
Martinez-Nicolas et al. (2011) ³⁸	Spain	Cross-sectional, volunteer sample N = 88	Undergraduate volunteers 18-23 years 64% female	HBO Pendant Temperature/Light Data Logger (Onset Computer, Bourne, Massachusetts, USA)	Self-reported sleep diary designed by Chronobiology Laboratory of University of Murcia, Spain.	Mean Intensity Morning light Evening light	Stability of sleep-wake rhythm Sleep fragmentation Midsleep	A higher mean intensity ($r = .343$, $p < 0.01$) as well as more light in the morning ($r = .437$, $p < 0.001$) and evening ($r = .304$, $p < 0.01$) were associated with a more stable sleep-wake rhythm. None of the light exposure measures were associated with the sleep fragmentation. A higher mean intensity was associated with an earlier midpoint of sleep ($r = -.425$, $p < 0.01$). Stronger morning light exposure ($r = -.651$, $p < 0.001$) as well as evening light exposure ($r = -.287$, $p < 0.01$) were associated with phase advance measured in terms of sleep midpoint.	poor

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measure-ment: Light exposure	Measure-ment: Sleep-wake rhythm	Light exposure outcome	Sleep-wake rhythm outcome	Results	RoB*
Phillips et al. (2017) ³³	U.S.A.	Cross-sectional, volunteer sample N = 22	Full-time undergraduates (excluding first-years) from Harvard College 20.23 years (SD = 1.27) 48% female	Motionlogger-L (Ambulatory Monitoring, Inc., Ardsley, NY)	Dim Light Melatonin Onset	Light exposure in lux	Dim Light Melatonin Onset (DLMO)	A previously validated model of the human circadian pacemaker; its sensitivity to light, and salivary melatonin concentration was used to predict circadian phase. Modelling the circadian pacemaker showed that irregular sleepers have a 1.7 hour delay of their circadian timing predominantly due to the characteristics of their light profiles ($p < 0.01$, t-test).	fair
Van der Maren et al. (2018) ³⁴	Canada	Cross-sectional, volunteer sample N = 28	Sleep delayed group: 21.3 years (SD = 1.2) 57% female Control group: mean age 22.1 years (SD = 2.5) 57% female	Actiwatch-2 (Philips-Respironics, Andover, MA)	DLMO	Mean white light exposure Mean blue light exposure Light exposure amplitude	Dim Light Melatonin Onset (DLMO)	The association between averaged daily exposure to white light and DLMO was non-significant ($r = -.29$, $p = 0.14$). More exposure to blue light was related to an earlier DLMO ($r = -.46$, $p = 0.01$). A lower light exposure amplitude was associated with a later DLMO for both white ($r = -.61$, $p = 0.001$) and blue light ($r = -.53$, $p = 0.004$).	good
Wallace-Guy et al. (2002) ²⁷	U.S.A.	Cross-sectional, convenient sample N = 154	Menopausal women included in a ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume, Ambulatory Monitoring Inc., Ardsley, NY	Actilume, Ambulatory Monitoring Inc., Ardsley, NY	Mesor logLux Light exposure 4 hours prior to sleep onset	Sleep onset latency Waking after sleep onset Total night sleep Total day sleep	Greater 24-hour light exposure was related to shorter sleep latencies ($r = -.29$, $p < .001$) and waking after sleep onset ($r = -.19$, $p < .05$), but not with total night or day sleep. Illumination during the 4 hours before bedtime was not significantly related to total sleep time, sleep latency, sleep timing, or amount of daytime napping.	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measure-ment: Light exposure	Measure-ment: Sleep-wake rhythm	Light exposure outcome	Sleep-wake rhythm outcome	Results	RoB*
Wams et al. (2017) ³⁶	the Netherlands	Cross-sectional, volunteer sample n = 20	Healthy participants 23.4 years (SD = 2.2) 60% female	Motion-watch 8 (8 [™] , MW8 [™] , CamNTech Ltd., UK)	Motion-watch 8 (8 [™] , MW8 [™] , CamNTech Ltd., UK) Polysomnography (PSG)	Light exposure in log Lux Time of first exposure above 10 lux Time of last exposure above 10 lux Time of maximum light exposure	Dim Light Melatonin Onset (DLMO) % Rapid Eye Movement (REM) sleep % stage 1 sleep REM latency Mean awakenings per hour Time in bed Waking after sleep onset No. of transitions Rest duration Sleep onset Sleep offset	Raw maximal light intensity, time of first exposure to >10 lux, time of last exposure to 10 lux, and time of maximal light exposure were not related to DLMO. Higher fitted average light intensity did predict earlier DLMO ($R^2 = 0.23$, $\chi^2(2) = 10.01$, $p < .01$). Higher maximal intensity of light on the day before PSG was followed by lower percentages of REM sleep ($R^2 = 0.43$, $\chi^2(2) = 13.90$, $p < .001$). Increase in percentage of SWS at higher average light intensities subsequent over the day ($R^2 = 0.25$, $\chi^2(2) = 8.8$, $p < .05$). A later time of first exposure to >10 lux ($R^2 = 0.21$, $\chi^2(1) = 0.36$, $p < .05$) and a later timing of maximal light exposure ($R^2 = .36$, $\chi^2(2) = 11.17$, $p < .01$) were associated with a subsequent shorter latency to first REM episode. Lower maximal light intensity was associated with longer rest duration ($R^2 = 0.05$, $\chi^2(2) = 4.82$, $p < .05$) and fewer awakenings per hour ($R^2 = 0.26$, $\chi^2(2) = 6.98$, $p < .05$). No significant results for waking after sleep onset, number of transitions, time in bed, sleep onset and offset were reported.	good

*RoB: risk of bias

Table 3. Characteristics of included studies examining the association between personal light exposure and sleep quality in the general population.

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measure: Light exposure	Measure: Sleep quality	Light exposure outcome	Sleep quality outcome	Results	RoB*
Boubekri et al. (2014) ³⁹	U.S.A.	Cross-sectional, convenient sample N = 21	Volunteers from office locations with and without windows. Descriptives of this sample not reported, descriptives below are for the full sample of 49 participants. 19-60+ years 61.22 % female	Actiwatch-L (Minimitter)	Actiwatch-L (Minimitter) Pittsburgh Sleep Quality Index	Average light exposure	Sleep efficiency Sleep quality	There was no difference between workers with and without windows in objectively measured sleep efficiency (with windows: 91%, without windows: 89%, $p < .10$). Workers with windows scores lower on the Pittsburgh Sleep Quality Index (5.05 versus 7.23, $p = .05$), indicating a better sleep quality when compared to workers without windows.	fair
Figueiro et al. (2016) ⁴⁰	U.S.A.	Cross-sectional, volunteer sample N = 11	Workers of the Building of the U.S. General Services Administration in Grand Junction, Colorado Age not reported 91% female	The Daysimeter (Lighting Research Center, Troy, NY)	Pittsburgh Sleep Quality Index PROMIS Sleep Disturbance Short Form	Magnitude of circadian stimulus calculated using light exposure and circadian illuminance (CS).	Sleep quality Sleep problems	None of the correlations between CS values and self-reports of sleep quality and sleep problems were statistically significant.	poor

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Sleep quality	Light exposure outcome	Sleep quality outcome	Results	RoB*
Figureiro et al. (2017) ⁴¹	U.S.A.	Cross-sectional, volunteer sample N = 67	Workers in 5 buildings of the U.S. General Services Administration in Washington DC (2x), Portland OR, Seattle WA, Grand Junction Colorado Age not reported 63% female	The Daysimeter (Lighting Research Center, Troy, NY)	Pittsburg Sleep Quality Index PROMIS Sleep Disturbance Short Form	Morning or workday CS; Magnitude of circadian stimulus calculated using light exposure and circadian illuminance (CS) in the morning or workday (high vs low)	Sleep quality Sleep quality outcome	Participants with high workday CS had significantly better sleep quality ($F_{1,155} = 6.19, p = .014$) and fewer sleep disturbances ($F_{1,165} = 4.76, p = .031$) than those with low workday CS. No effect was found for high or low morning CS and sleep quality or sleep problems.	fair
Hubalek et al. (2010) ¹⁹	Switzerland	Cross-sectional, volunteer sample N = 23	Healthy workers in offices located in or close to Zurich, Switzerland 38.4 years (SD = 10.6) 30% female	LuxBlick (no manufacturer reported)	Sleep Quality Questionnaire	Daily light exposure Light exposure over thresholds 1000 and 2500 lux Vis-novis spectrum parameter (ratio image forming and non-image forming light exposure)	Sleep quality	Sleep quality positively correlated with all measures of daily luminous exposure. Spearman's correlations for 25 th – 90 th percentile of illuminance and irradiance were .368 and .963 ($p < 0.001$). Correlations for duration over thresholds >100 lux, >1000 lux and > 2500 lux were .726, .906 and .915 (all $p < .001$)	good

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Sleep quality	Light exposure outcome	Sleep quality outcome	Results	RoB*
Kripke et al. (2004) ²⁵	U.S.A.	Cross-sectional, convenient sample N = 416-450	Menopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Sleep diary	Mesor Log Lux	Sleep problems Sleep quality	Mesor log lux was positively correlated with sleep quality ($r_p = .17, p < .005$) and negatively correlated with trouble falling asleep ($r_p = -.17, p < .005$), waking after sleep onset ($r_p = -.18, p < .001$), early waking ($r_p = -.09, p < .10$) and trouble getting back to sleep ($r_p = -.11, p < .025$).	fair
Wallace-Guy et al. (2002) ²⁷	U.S.A.	Cross-sectional, convenient sample N = 154	Menopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Light exposure 4 hours prior to sleep onset	Sleep efficiency	Illumination during the 4 hours before bedtime was not significantly related to sleep efficiency.	fair
Wams et al. (2017) ³⁶	the Netherlands	Cross-sectional, volunteer sample N = 20	Healthy volunteers 23.4 years (SD = 2.2) 60% female	Motionwatch 8 (8 th , MW8 th , CamNTech Ltd., UK)	Pittsburgh Sleep Quality Index	Light exposure in log Lux Timing of first exposure above 10 lux Timing of maximum light exposure	Sleep quality	Amount of light exposure was not related to sleep quality. Individuals who were first exposed to 10 lux later had significantly lower subjective reported sleep quality ($r = -2.5, p = .02067$).	good

*RoB: risk of bias

With regard to the timing of light exposure, the fair study found an association between exposure and the amount of light exposure in the morning and phasor magnitudes ($F_{1,45} = 41,94, p < .0001$)⁴². In the poor study, a greater amount of light exposure in the morning ($r = .437, p < .001$) and evening ($r = .304, p < .01$) was associated with a more stable rest-activity rhythm³⁸.

Overall, based on two lower-quality studies^{38,42} with consistent results, it is concluded that limited evidence is available for a positive relationship between the amount and timing of light exposure and rest-activity rhythms.

Circadian phase of sleep-wake rhythm One good-quality study found a positive relationship between the amount of light exposure and DLMO ($R^2 = 0.23, \chi^2 (2) = 10.01, p < .01$), whereas maximal light exposure in lux was not related to DLMO³⁶. Another good-quality study found no relationship between the amount of white light and DLMO, but more exposure to blue light was related to an earlier DLMO ($r = -.46, p = .01$)³⁴. A fair-quality study showed light exposure mesor was not related to timing and mesor of melatonin³⁰. Another fair study found that total duration of light exposure above any level of light exposure did not correlate with DLMO³⁵.

With regard to timing of light exposure, the good-quality study did not find a relationship between timing of light exposure and DLMO³⁶. A fair study found a medium to strong ($r = .49-.77$) positive relationship between the timing of first and last light exposure and DLMO; later exposure to light was related to later DLMO³⁵. Another fair study compared DLMO timing in regular and irregular sleepers, and concluded that the 1.7 h delay of DLMO in irregular sleepers ($p < 0.01$) was the result of their delayed timing of light exposure³³. The last fair study showed later light exposure acrophase was related to lower melatonin mesor ($r = -.43, p = .03$) but not to melatonin acrophase³⁰.

Given the two high-quality studies^{34,36} that found a positive relationship between the amount of light exposure and DLMO and two fair-quality studies^{30,35} that did not find a significant relationship, the available studies provide conflicting evidence on the association between light exposure and DLMO. Given the one high-quality study³⁶ that did not find a relationship and three fair studies that found a positive relationship between timing of light exposure and DLMO^{30,33,35}, the evidence for an effect of the timing of light exposure on DLMO is conflicting too.

Sleep architecture The highest-quality study showed exposure to light of higher intensity was associated with a lower percentage of stage 1 sleep ($p = .03$), shorter REM sleep duration ($R^2 = .43, \chi^2 (2) = 13.90, p < .001$), and longer slow wave dura-

tion on PSG ($R^2 = .25$, $\chi^2(2) = 8.86$, $p < .05$)³⁶. The amount of light exposure was not associated with the percentage of stage 2, 3 and REM sleep, N3 latency, and REM sleep latency³⁶. A fair study showed that L5 onset, the start of the five hours with the least amount of activity during the night, was earlier when participants were exposed to a higher amount of light during the day ($r = -.23$, $t(60) = -2.58$, $p = 0.012$)⁴¹. Sleep fragmentation was not associated with the amount of light exposure in one fair study and one poor study^{38,39}.

The highest-quality study showed that later timing of first exposure to >10 lux ($R^2 = 0.21$, $\chi^2(1) = 5.77$, $p < .05$) and later timing of maximal light exposure ($R^2 = 0.36$, $\chi^2(2) = 11.17$, $p < .01$) were associated with a subsequent shorter latency to first REM episode³⁶. Timing of light exposure was not associated with the percentage of stage 2, 3 and REM sleep, N3 latency, and REM sleep latency³⁶. A fair study found nocturnal activity was not associated with the amount of evening light exposure⁴¹. A poor study found a higher amount of light exposure in the morning ($r = -.651$, $p < 0.001$) as well as evening light exposure ($r = -.287$, $p < 0.01$) was associated with an earlier sleep midpoint³⁸.

The high-quality study³⁶ as well as the two lower-quality studies^{38,41} found evidence for a positive relationship between the amount and timing of light exposure and some estimates of sleep architecture, but due to the broad variety of outcomes this evidence is classified as limited.

Sleep timing One high-quality study³⁶ and two fair-quality studies^{41,42} measured sleep onset time (hh:mm, clock time of sleep start); only one fair-quality study found that the amount of light exposure during the day ($r = -.41$, $t(60) = -3.49$, $p < 0.001$) and low evening light exposure ($r = .61$, $t(60) = 5.93$, $p < 0.001$) were associated with an earlier sleep onset⁴¹. The high-quality study found sleep offset time (hh:mm, clock time of sleep end) and time in bed (minutes between getting into bed in the evening and out of bed in the morning) not to be associated with the timing or exposure to high light intensity³⁶.

The high-quality study³⁶ and one study of fair quality⁴² found no relationship between light exposure and sleep timing, whereas one fair-quality study⁴¹ did find a significant relationship. Thus the available studies provide conflicting evidence for a relationship between the amount and timing of light exposure and bedtimes.

Nocturnal sleep duration and daytime napping The only high-quality study found lower light intensities to be related to longer nocturnal sleep duration ($R^2 = 0.05$, $\chi^2(1) = 4.83$, $p < .05$) (Wams et al., 2017). The three fair-quality studies found the amount of light exposure and nocturnal sleep duration were positively ($r = 0.483$,

$p = 0.03$)³⁹, negatively (Kripke et al. (2004)²⁵: $r_p = -.20$, $p < 0.001$); or not²⁷ associated. Subjective nocturnal sleep duration²⁵ and duration of daytime napping were not associated with exposure to high light intensities^{25,27}.

The single high-quality³⁶ and three fair-quality studies^{25,27,39} provide conflicting evidence on the relationship between the amount of light and sleep duration.

Sleep onset latency The single high-quality study found light intensity not to be related to sleep onset latency³⁶. One fair study found that exposure to higher light intensities was associated with a shorter sleep onset latency ($r = -.29$, $p < 0.001$)²⁷, whereas another fair study did not find an association³⁹.

The high-quality study³⁶ as well as two studies of fair quality^{27,39} found no association between timing of light exposure and sleep onset latency. One fair study found high light exposure in the morning to be associated with shorter sleep onset latency in the following night ($F_{1,15} = 10.43$, $p = .005$)⁴².

Based on one high-quality study³⁶ and three lower-quality studies^{27,39,42}, the evidence on the relationship between amount and timing of light and sleep onset latency is conflicting.

Waking after sleep onset The high-quality study of Wams et al. (2017)³⁶ found that lower maximal light exposure ($R^2 = .26$, $p < .05$) and earlier timing ($R^2 = .36$, $p < .05$) of light exposure resulted in fewer awakenings measured using actigraphy, but not when using PSG. Fair-quality studies found a longer duration of light exposure ($R^2 = .519$)³⁷ and earlier light exposure (Wallace-Guy et al. (2002)²⁷: $r = -.29$, $p < .05$) were associated with fewer nocturnal awakenings. In contrast, the fair-quality study of Boubekri et al. (2014)³⁹ did not find an association between the amount and timing of light exposure and wake after sleep onset (minutes). The single high-quality study³⁶ and three fair-quality studies^{27,37,39} provide conflicting evidence on the relationship between the amount and timing of light and waking after sleep onset.

Sleep quality Exposure to higher light intensities was associated with better sleep quality in one high-quality study ($F_{1,81.1} = 6.84$, $p = .01$)¹⁹; the other high-quality study did not find this relationship³⁶. Three fair-quality studies found exposure to higher light intensities to be associated with better sleep quality (Kripke et al. (2004)²⁵: $r_p = 0.17$, $p < 0.005$; Figueiro et al. (2017)⁴²: $F_{1,155} = 6.19$, $p = .014$; Boubekri et al. (2014)³⁹: $p = .05$). One poor study found no association between the amount of light and sleep quality^{36,40}.

One high-quality study found a longer duration of light exposure > 1000 lux ($F_{1,76.2} = 4.22$, $p = .04$) and > 2500 lux ($F_{1,81.3} = 6.82$, $p = .01$) during the waking day

to be positively related to sleep quality¹⁹. The other high-quality study and a fair-quality study found earlier timing of light exposure to be related to better sleep quality (Wams et al. (2017)³⁶: $t(1) = -2.5$, $p = 0.0267$; Figueiro et al. (2017)⁴²: $F_{1,165} = 4.76$, $p = .031$), whereas the other fair study did not find timing to be related to sleep quality²⁷.

Two fair studies found exposure to higher light intensities to be associated with fewer sleep disturbances (Kripke et al. (2004)²⁵: falling asleep; $r_p = -0.17$, $p < 0.005$; night waking: $r_p = -0.18$, $p < 0.001$; trouble getting back to sleep $r_p = -0.11$, $p < 0.025$; Figueiro et al. (2017)⁴²: $F_{1,21} = 6.12$, $p = .022$). One study of poor quality found no association between the amount of light and sleep problems⁴⁰.

The available studies provide conflicting evidence for the amount and timing of light exposure and sleep quality and the association between higher light intensities and sleep problems. No evidence is presented for the timing of light exposure and sleep problems.

Mood

Assessment of mood

The 16 studies on light exposure and mood are described in Table 4. All included studies used questionnaires to assess mood^{19,25-29,31,34,40,42-47,49}. Depressive symptoms were measured in nine studies^{25,27,28,31,40,42,44,47,48}. Cyclothymic and hyperthymic temperament were measured in two studies^{28,29}, the presence of mood disorders was measured in one study²⁵, and affect in seven studies^{19,28,40,43,45,46,49}. Other mood-related measurements were emotional well-being²⁶ and quality of life²⁶.

Association between light exposure and mood

Depression and temperament Nine studies looking at depression and temperament were of fair quality, two studies were of poor quality^{40,42}. Three studies found that exposure to higher amounts of light was associated with fewer depressive symptoms (Wallace-Guy et al. (2002)²⁷: $r = -0.21$, $p = .01$; Figueiro et al. (2017)⁴²: $F_{1,44} = 4.68$, $p = .036$; Espiritu et al. (1994)⁴⁴: $r = -.191$, $p = .026$), six studies did not find a significant association^{25,28,31,40,47}. Duration of light exposure was not related to depressive symptoms⁴⁸. One study found higher levels of light exposure ($r = -1.191$, $p = 0.026$) and longer duration (>10 lux: $r = .226$, $p = 0.01$; >100 : $r = -.252$, $p = 0.005$; >1000 : $r = -.217$, $p = 0.013$) of light exposure to be associated with fewer Seasonal Affective Disorder symptoms⁴⁴. Exposure to light of higher intensity was related to a more hyperthymic (Hoaki et al. (2011)²⁹: $b = .59$, $p < .0001$); Araki et al. (2012)²⁸: $R^2 = .32$, $b = .54$, $p < .0001$), and less cyclothymic state ($R^2 = .323$, $b = .54$, $p < .0001$)²⁸, but was not associated with a diagnosis for mood disorders

Table 4. Characteristics of included studies examining the association between personal light exposure and mood and affect in the general population.

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	RoP*
van Rossum et al. (2008) ⁴³	Canada	Cross-sectional, volunteer sample N = 53	Mild seasonal individuals, defined by a Global Seasonality Scale score between 6-11 31 years (SD = 8) 54% female	Actiwatch-Light (Mini Mitter, Inc., Bend, OR, USA)	Affect Valence and Affect Arousal Positive Affect	Overall bright light exposure (BLE) Groups: no, low (<19,6min) and high (>19,6 min) Bright light exposure	Affect Valence Affect Arousal Positive Affect	Bright light exposure was positively associated with affect valence ($F_{2,89} = 3.89, p < 0.03$), affect arousal ($F_{2,89} = 10.21, p < 0.0001$) and positive affect ($F_{2,89} = 11.66, p < .0001$). The difference in affect valence between participants with high and low BLE was significant ($t(89) = -2.68, p < 0.03$). The difference between high and no BLE was not significant. Compared to periods without BLE, participants reported higher affect arousal during periods with both low and high BLE (low: $t(89) = -4.36, p < 0.0002$; high: $t(89) = -3.30, p < 0.005$). After Tukey correction, the difference between low and high BLE was not significant. The differences in positive affect between participants with high, low and zero BLE ($t(89) = -2.91, p < 0.02$) and between high and zero BLE ($t(89) = -4.81, p < 0.0001$) were significant. The difference between high and low BLE was not significant.	good
Araki et al. (2012) ²⁸	Japan	Cross-sectional, volunteer sample N = 56	Healthy participants (no psychiatric disorders). 26.9 years (SD = 5.9) 30% female	Actigraphy with illuminance measurement (no specs reported)	Japanese standardized version of the Temperament Evaluation of Memphis, Pisa, Paris and San Diego-auto questionnaire version (TEMPS-A)	Average illuminance of daytime	Temperaments: Depressive Anxious Cyclothymic Hyperthymic Irritable	The association between light exposure and cyclothymic temperament was negative ($b = -.33, p = 0.015$), light exposure and hyperthymic temperament scores were positively ($b = .54, p < 0.0001$) associated. Light exposure was not associated with depressive temperament, or irritable and anxious temperament.	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	RoB*
Asai et al. (2018) ⁴⁸	Japan	Cross-sectional, volunteer sample n = 1005	Older adults Mean age 71.5 (SD = 7.0) 51.9 % female	Activwatch 2 (Responics Inc., Murrysville, PA, USA)	Short version of the Geriatric Depression Scale (GDS-15)	Minutes per day exposed to >1000 lux	GDS-score	Time exposed to light >1000 lux did not explain the relationship between farming habits and depressive symptoms. Further adjustment for log-transformed time exposed to bright light (≥ 1000 lx) and daytime physical activity (model 3 in Table 2) attenuated the significance of OR for depressive symptoms among long farming group (0.66, 95%CI: 0.42–1.03, $p = 0.07$); however, OR among short farming group remained significant (0.65, 0.43–0.99, $p = 0.047$) with significant trend ($p = 0.048$). Indirect association mediated by time exposed to bright light explained 7.2% of the direct association between farming habit and depressive symptoms, but it was not significant (95%CI: –15.6 to 31.0).	fair
Espiritu et al. (1994) ⁴⁴	U.S.A.	Cross-sectional, volunteer sample N = 106	Inhabitants from the City of San Diego, USA aged 40–64 49 years 50% female	Actillum (Ambulatory Monitoring Inc., Ardsley, NY)	Center for Epidemiologic Studies Depression Scale (CES-D) SAD-related questions from the SIGH-DAS-SR	Percent-age time of measurement period at thresholds 10, 100 and 1000 lux. Log lux mesor Log lux amplitude	Total score for CES-D Total score for SAD questions	SAD scores were negatively correlated with every illumination score. Correlations for the amount of time above 10, 100 and 1000 lux were respectively $-.227$ ($p = .005$), $-.252$ ($p = .013$) and $-.217$ ($p = .013$). The correlation with log lux mesor was $-.191$ ($p = .026$), and with log lux amplitude $-.280$ ($p = .002$). Scores for the CES-D did not correlate significantly with any of the light exposure measurements.	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	Rob*
Figureiro et al. (2016) ⁴⁰	U.S.A.	Cross-sectional, volunteer sample N = 11	Workers in the Building of the U.S. General Services Administration in Grand Junction, Colorado. Age not reported 91% female	The Daysimeter (Lighting Research Center, Troy, NY)	Positive and Negative Affect Schedule, Center for Epidemiologic Studies Depression Scale (CES-D)	Magnitude of circadian stimulus calculated using light exposure and circadian illuminance (CS)	Positive affect Negative affect CES-D score	None of the correlations between CS values and self-reports of affect and mood were statistically significant.	poor
Figureiro et al. (2017) ⁴²	U.S.A.	Cross-sectional, volunteer sample N = 67	Workers in 5 buildings of the U.S. General Services Administration in Washington DC (2x), Portland OR, Seattle WA, Grand Junction Colorado Age not reported 63% female	The Daysimeter (Lighting Research Center, Troy, NY)	Center of Epidemiological Studies Depression Scale (CES-D)	Magnitude of circadian stimulus calculated using light exposure and circadian illuminance (CS)	CES-D score	Participants with high workday CS had lower depression scores than those with low workday CS ($F_{1,144} = 4.68, p = .026$). No association was found for CS and positive or negative affect.	poor
Grandner et al. (2006) ²⁶	U.S.A.	Cross-sectional, convenient sample N = 459	Postmenopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.68 years (SD = 7.86) 100% female	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Quality of life and emotional well-being scales of the self-report questionnaires designed for the Women's Health Initiative	Average light exposure morning light exposure Light acrophase	Quality of Life Emotional Well-being	Emotional well-being scores were positively correlated with mesor light ($r = .128, p = 0.05$) but not with morning light. Quality of life was positively associated with mesor light ($n = 422, r = .185, p = 0.0005$) and morning light (when corrected for average light exposure, partial $F(1400)=5.760, p = 0.05, R^2$ change=0.013).	poor

Light acrophase did not correlate with quality of life and emotional well-being.

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	Rob*
Hoaki et al. (2011) ²⁹	Japan	Cross-sectional, volunteer sample N = 56	Healthy participants (no psychiatric disorders) 26.9 years (SD = 5.9) 30% female	Actigraphy with illuminance measurement (no specs reported).	Japanese standardized version of the Temperament Evaluation of Memphis, Paris and San Diego-auto questionnaire version (TEMPS-A)	Average illuminance during daytime	Hyperthymic temperaments	Daytime illuminance was positively associated with hyperthymic scores ($r = .47$). When corrected for adrenocorticotropic hormone and sleep time, daytime illuminance was a predictor for hyperthymic temperament scores ($b = .59, p < .0001$)	fair
Hubalek et al. (2010) ¹⁹	Switzerland	Cross-sectional, volunteer sample N = 23	Healthy workers with offices located in or close to Zurich, Switzerland 38.4 years (SD = 10.6) 30% female	LuxBlick (no manufacturer reported)	Pleasure-Arousal-Dominance (PAD)	Daily light exposure, light exposure over thresholds 1000 and 2500 lux and vis-nonvis spectrum parameter (ratio image forming and non-image forming light exposure)	Pleasure Arousal	None of the light exposure measures were related to feelings of pleasure or arousal.	good

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	RoB*
Itzhacki et al. (2019) ⁴⁹	The Netherlands	Cross-sectional, volunteer sample N = 27	mean age 23.7 years (SD= 3.8) 52% female	Daysimeter-D, (Rensselaer Polytechnic Institute, Troy, NY)	Positive and negative mood adjectives of the Daytime Insomnia Symptom Scale	Mean light intensity per time-frame	Mean score of the five Positive Mood items Mean score of the five Negative Mood items	Within-subject as well as between-subject variability in light intensity did not correlate significantly with positive mood or negative mood.	good
Jean-Louis et al. (2005) ³¹	U.S.A.	Cross-sectional, volunteer sample N = 70	Healthy older adults 68.27 years (SD= 5.97) 73% female	Activatch-L (Mini Mitter)	Geriatric Depression Scale (GDS)	Mesor log Lux Light exposure acrophase	GDS score	Amount and timing of light exposure were not associated with depressed mood.	fair
Koller et al. (1993) ⁴⁵	Austria	Cross-sectional, stratified sample N = 12	Night and day workers Night: 32.8 year (SD = 6.2) Day: 37.3 year (SD = 8.6) 100% male	Photocell BPW21 (Telefunken)	State Questionnaire	Average light exposure Onset of light exposure	Mood Alertness	Higher light dose in day workers associated with a shift in the maximum mood score to later in that same day ($r = .90$). Regression analyses showed that 40% of the variation in mood or alertness is explained by the light onset.	poor

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	RoB*
Kripke et al. (2004) ²⁵	U.S.A.	Cross-sectional, convenient sample N = 416-450	Menopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Center of Epidemiologic Studies Depression Scale (CES-D)	Mesor Log Lux	CES-D score Affective Disorders	Mesor Log Lux was not associated with CES-D depression scores or SCID mood disorders.	fair
Smolders et al. (2013) ⁴⁶	The Netherlands	Cross-sectional, volunteer sample N = 42	Office employees and students that all lived, worked, and/or went to university in the Eindhoven region, the Netherlands 25 years (SD = 8.1) 52 % female	Daysimeter (Lighting Research Center, Troy, NY)	Online Questionnaire	Average light level per hour Percentage of minutes above 1000 lux per hour	Vitality Tension Positive affect Negative affect	Hourly light exposure was positively related to vitality: when corrected for chronotype, social interaction, physical effort, prior sleep duration and light sensitivity and subjective chronic fatigue, participants felt more energetic when they had experienced a higher amount of light during the previous hour ($\chi^2(3) = 359.12; p < .01, B_{\text{hourly light}} = .06, p < .01$). Light exposure was not related to feelings of tension, positive or negative affect.	fair
Wallace-Guy et al. (2002) ²⁷	U.S.A.	Cross-sectional, convenient sample N = 154	Menopausal women included in an ancillary study of the Women's Health Initiative (Matthews et al. 1997) 67.7 years (SD = 7.9) 100% female	Actilume (Ambulatory Monitoring Inc., Ardsley, NY)	Screening questionnaire for major depression	Mesor log Lux	Depressed mood	Greater 24-hour light exposure was related to lower depressed mood ($r = -.21, p = .01$).	fair

Author	Country	Design, sampling, sample size	Participant characteristics (age, gender)	Measurement: Light exposure	Measurement: Mood	Light exposure outcome	Mood outcome	Results	RoB*
Wang et al. (2003) ⁴⁷	U.S.A.	Cross-sectional, volunteer sample N = 37	Postpartum women 15 postpartum Age 32 (SD= 8.43) 100% female	The Actillum (Ambulatory Monitoring, Inc., Ardsley, NY)	Short version of the Center of Epidemiological Studies Depression Scale	Average light exposure	Mood	Average light exposure was not correlated with mood.	fair

*RoB: risk of bias

diagnosed using the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID interview)^{25,53}.

Based on the low quality of the studies, the diversity of the outcomes, and conflicting results, it is concluded that the available studies provide conflicting evidence for an association between the amount of light exposure and depression and temperament.

Affect, overall emotional well-being, and quality of life One study of good quality found the amount of light exposure was associated with positive affect ($F_{2, 89} = 11.66, p < .0001$)⁴³, but in a poor-quality study these were not found to be associated⁴². The amount of light was associated with more vitality ($b = .08; p < .01$)⁴⁶. Other measurements of affect, for instance negative affect, were not related to measures of light exposure^{19,28,40,42,43,46,49}.

Exposure to a higher amount of light was related to better emotional well-being ($r = .128, p = 0.05$) and a higher quality of life ($r = .185, p = 0.0005$), whereas exposure to more light in the morning was associated with quality of life (when corrected for average light exposure, partial $F(1400) = 5.760, p = 0.05, R^2 \text{ change} = 0.013$) but not with emotional well-being²⁶. Light acrophase was not related to either quality of life or emotional well-being.

Based on the low quality of the studies, the diversity of the outcomes, and the lack of significant results, it is concluded that the available studies provide very limited evidence for an association between the amount of light exposure and affect, emotional well-being, and quality of life.

DISCUSSION

This systematic review describes the association between habitual personal light exposure, sleep-wake rhythm, and mood in the general healthy adult population. The 25 articles included in this review mainly focused on the average light intensity in lux of light exposure during the day and the duration and timing of the light exposure. The quality assessment of the 25 included papers revealed a risk of bias in all studies, largely due to gaps in the information reported and because most of the studies were cross-sectional. Limited evidence is presented for a positive relationship between the amount and timing of light exposure on rest-activity rhythm and some estimates of sleep architecture. For the association between light exposure and circadian phase of the sleep-wake rhythm, sleep estimates, sleep quality, and mood, the evidence is conflicting.

The two high-quality studies on light exposure and circadian phase of sleep-wake rhythm provided conflicting results, which is not in line with the laboratory studies conducted previously. These show that light sources of just 8 lux can shift the phase of the sleep-wake rhythm^{54,55}. Although circadian phase of the sleep-wake rhythm seems to be affected by light exposure within the laboratory setting, the implications for the real world are yet to be determined. Second, there is no consensus on what “an optimal aligned circadian rhythm is” or what a cut-off point is for desynchronization of the rhythms⁵⁵. As all the studies included were cross-sectional and measured circadian phase as a continuum, this review unfortunately cannot give insight into this matter.

Five out of six studies (two of high quality, three of fair quality) on sleep quality found a positive relationship between light exposure and sleep quality, while results for several sleep indicators are conflicting. It is hypothesized that the measurements of sleep quality capture an overall association between light exposure and sleep, whereas the different sleep indicators are possibly too specific. Decades of sleep research show a broad variety in sleep preference; some people feel energetic after 8 hours whereas others report a need for 10 hours of sleep. This subjective experience of sleep quality, even more than the objective sleep, is an important criterion in diagnosing sleep problems⁵⁶. Therefore, it is suggested that the results of the review on light exposure and sleep quality might provide more valuable information than the results of the sleep indicators.

The limited evidence for an association between personal light exposure and rest-activity rhythm and sleep architecture does not seem to translate directly to sleep estimates and mood outcomes. The results of the current review were inconclusive for the effect of light exposure on sleep estimates and mood. In these cases, the personal preference, or “chronotype,” could provide more insight. Roughly 15% of the population identify as an early chronotype or “lark”. Larks are characterized by waking up early in the morning, and falling asleep early in the evening. Another 15% of the population identify as a late chronotype or “owl” and wake up and go to bed later in the day. The remaining 70% have an “intermediate” chronotype^{57,58}. Research showed that owls are more prone to depression and anxiety^{59,60} and sleep longer⁶¹ than larks. If chronotype is a mediator or confounder for the relationship between light exposure, sleep, and mood, more and earlier light exposure could have a positive relationship with outcomes for larks, and a negative one for owls. It is hypothesized that since chronotype was not taken into account in the included studies, the possible different associations between light exposure and sleep for larks and owls offset one another in the results, resulting in the non-significant results found.

Another explanation for the lack of conclusive results on light exposure and sleep might be provided by the age of the study sample subjects. The aging brain is less sensitive to light exposure⁶², possibly resulting in more light needed to affect sleep. For sleep we included three studies with an older study sample^{25,27,37}, one with a young sample³⁶ and two with a mixed-age study sample^{39,41}. Further inspection of the results of these studies did not provide more insight, as studies with both younger and older subjects showed an association between light exposure and sleep for some measures but not for others.

Finally, the ambiguous results might be explained by the fact that the included studies did not correct for other factors that are known to affect the sleep and mood. Whereas most of the studies corrected for age, they did not take into account other “Zeitgebers” and factors that can affect sleep and mood, like physical activity, working times, diet, or medication use^{63,64}.

A disadvantage of the included studies is that only a third of the studies measured the light exposure prior to the outcome measurements. Light is shown to have a direct effect on mood and sleep^{3,54} in the lab setting, so it is desirable to analyze mood or sleep in respect of the personal light exposure on that same day. Of the 25 papers included in this review, only five studies analyzed the data in this manner. Secondly, in order to give a direction to the studied relationship between light exposure, sleep-wake rhythm and mood, it is required that studies measure exposure prior to the outcome and at least at two time points. Unfortunately, as all studies were cross-sectional and most just performed correlational analyses, no conclusion can be drawn on the causal relationship between light exposure, sleep-wake rhythm and mood.

In line with the above, most of the included studies were not designed to answer the research question of this review. It is hypothesized that some of the included papers reported baseline data of intervention studies. Other papers were by-catch from other studies that happened to have measured both light exposure and outcomes of interest. This was first noticed in the data extraction; studies would report light exposure and mood or sleep outcomes, but no analyses relating these variables. Second, some study populations were part of a bigger cohort in which the wrist-worn accelerometer was used and the light exposure data was analyzed in an exploratory fashion.

Lastly, 19 studies measured personal light exposure using a wrist-worn light cell, which has been shown to be unreliable. Aarts et al. (2017)⁵⁰ showed that even within the same wrist-worn devices, the measured light exposure can differ by up to 27% from the actual light exposure. Therefore, measurements of light exposure in the included studies might have been unreliable and might have resulted in the ambiguous results.

Strengths and Limitations

Due to the large variation in outcome measures, conducting a meta-analysis was not possible for the current review. In addition, another limitation is that “grey literature” and papers in a language other than English were not included.

One strength of our systematic review is the duplicate study selection and quality assessment, which was performed by two authors independently. Second, the current review applied strict inclusion criteria for light exposure measurements and analysis. This way, even though the quality of the included studies was low, this review provides us with more insight into the current evidence on the relationship between personal light exposure, sleep, and mood in the general population.

Future Research

Further research should first and foremost be focused on better measurements of personal light exposure. Instead of measuring light exposure on the wrist, it is advised to measure light exposure at eye level or at least chest height as this is more reliable. In addition, measurement of the spectral properties of the light exposure is advised to gain insight into the properties of light that are the most efficient in entraining the circadian rhythms.

In order to gain insight into the causal relationship between light exposure and health, a high-quality, longitudinal intervention study of light exposure, sleep-wake rhythm and mood is needed. In this study, special attention should be given to measuring possible confounders of this relationship, like mental and physical condition, medication use, physical activity, and diet.

Most of the previous work on the association between circadian rhythms and health outcomes was based on populations that are prone to misalignment of the circadian rhythms. The current review provides insight into the relationship between light exposure, sleep-wake rhythm and sleep problems in the general population. This review gives grounds for integrating personal light measurements in research on light exposure and health in the populations that are at risk of extreme misalignment of the sleep-wake rhythm, in order to be able to define the mechanism of this relationship more clearly.

Conclusion

The current review aimed to describe the association between personal light exposure in the habitual setting, sleep-wake rhythm, and mood in the general population. Because the quality of the included studies was generally low, this review cannot do more than provide a first exploration of the available literature on this matter. Based on the available studies, we conclude that there is limited

evidence for a positive relationship between the amount and timing of light exposure on the one hand and rest-activity rhythms and some estimates of sleep architecture on the other hand. The evidence on the association between light exposure and circadian phase of the sleep-wake rhythm, sleep estimates, sleep quality, and mood is conflicting. High-quality intervention studies are needed to gain insight into the causal mechanism of this relationship.

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APPENDIX. DATABASE SPECIFIC SEARCHES

Embase.com: 3832

('light exposure'/exp OR 'latitude'/de OR 'sunbathing'/de OR 'sunlight'/de OR (((light) NEAR/3 (exposur*)) OR sunbath* OR sun OR sunlight OR daylight OR Antarctic* OR arctic OR 'north-pole' OR 'south-pole' OR ((high* OR increas*) NEAR/3 (latitude*))) :ab,ti) **AND** (wellbeing/de OR 'psychological well-being'/de OR 'psychological wellbeing assessment'/de OR 'emotion'/exp OR 'sleep'/exp OR 'sleep waking cycle'/de OR 'sleep disorder'/de OR 'circadian rhythm'/de OR 'depression'/exp OR (wellbeing OR ((well) NEXT/1 (being)) OR emotion* OR mood* OR happiness* OR unhappiness* OR fear* OR *anxi** OR *affective** OR *affection** OR *apath** OR anger OR sleep* OR circadian* OR (('day night' OR diurnal) NEXT/1 (rhythm* OR cycle OR pattern* OR variation*)) OR depressi* OR *optimism** OR *pessimism**) :ab,ti) **NOT** (([animals]/lim OR *plant/exp*) NOT [humans]/lim) **NOT** ('Conference Abstract' OR 'Letter' OR 'Note' OR 'Editorial')/it **AND** [english]/lim

Medline Epub (Ovid): 3377

("Sunbathing"/ OR exp "Sunlight"/ OR (((light) ADJ3 (exposur*)) OR sunbath* OR sun OR sunlight OR daylight OR Antarctic* OR arctic OR "north-pole" OR "south-pole" OR ((high* OR increas*) ADJ3 (latitude*))) .ab,ti.) **AND** (exp "Emotions"/ OR exp "Sleep"/ OR exp "Sleep Wake Disorders"/ OR "Circadian Rhythm"/ OR "Depression"/ OR (wellbeing OR ((well) ADJ1 (being)) OR emotion* OR mood* OR happiness* OR unhappiness* OR fear* OR *anxi** OR *affective** OR *affection** OR *apath** OR anger OR sleep* OR circadian* OR (("day night" OR diurnal) ADJ1 (rhythm* OR cycle OR pattern* OR variation*)) OR depressi* OR *optimism** OR *pessimism**) .ab,ti.) **NOT** ((exp Animals/ OR exp Plants/) NOT Humans/) **NOT** (congresses OR letter OR editorial).pt. **AND** (English).lg.

PsycInfo (Ovid): 2029

((((light) ADJ3 (exposur*)) OR sunbath* OR sun OR sunlight OR daylight OR Antarctic* OR arctic OR "north-pole" OR "south-pole" OR ((high* OR increas*) ADJ3 (latitude*))) .ab,ti.) **AND** (exp "Emotions"/ OR exp "Sleep"/ OR exp "Sleep Disorders"/ OR "Sleep Deprivation"/ OR "Human Biological Rhythms"/ OR exp "Emotions"/ OR "Well Being"/ OR (wellbeing OR ((well) ADJ1 (being)) OR emotion* OR mood* OR happiness* OR unhappiness* OR fear* OR *anxi** OR *affective** OR *affection** OR *apath** OR anger OR sleep* OR circadian* OR (("day night" OR diurnal) ADJ1 (rhythm* OR cycle OR pattern* OR variation*)) OR depressi* OR *optimism** OR *pessimism**) .ab,ti.) **NOT** (congresses OR letter OR editorial).pt. **AND** (English).lg.

Web of Science: 4336

TS=((((light) NEAR/2 (exposur*)) OR sunbath* OR sun OR sunlight OR daylight OR Antarctic* OR arctic OR "north-pole" OR "south-pole" OR ((high* OR increas*) NEAR/2 (latitude*)))) AND ((wellbeing OR ((well) NEAR/1 (being)) OR emotion* OR mood* OR happiness* OR unhappiness* OR fear* OR *anxi** OR *affective** OR *affection** OR apath* OR anger OR sleep* OR ("day night" OR diurnal OR circadian*) NEAR/1 (rhythm*)) OR *depressi** OR *optimism** OR *pessimism**) NOT ((animal* OR mouse OR mice OR murine OR rat OR rats OR insect* OR plants OR plant) NOT (human* OR patient*)) AND DT=Article AND LA=English

Google Scholar: 200 (top relevant refs)

"light exposure"|sunlight|daylight *wellbeing*|emotions|emotional|mood|anxiety|sleep|circadian|depression|depressive

4

Shedding light on light exposure in older adults with intellectual disabilities

Mylène N. Böhmer, Marlies J. Valstar, Mariëlle P.J. Aarts, Patrick J.E. Bindels, Aylt Oppewal, Eus J.W. van Someren, Dederieke A.M. Festen

Böhmer MN, Valstar MJ, Aarts MPJ, et al. Shedding light on light exposure in elderly with intellectual disabilities. *Journal of Intellectual Disability Research*. 2021. <https://doi.org/10.1111/jir.12822>

ABSTRACT

Background Light exposure affects mood and sleep regulation. Sleep problems and mood complaints are common in older adults 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 older adults with ID.

Methods The study sample consists of 82 older adults with ID (aged 62.3 ± 9.4 years) living in 16 residential homes of three care organizations 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 an 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. Older adults with ID spend most of their waking day (mean duration= 14:32:43 hours) in dim light (1-500 lux) environment and spend a median of 32 minutes in light > 1000 lux. Within participants, the threshold associated with better sleep (> 50 minutes of light >1000 lux) is reached for 34% of the days, the threshold associated with less depressive symptoms was (> 30 minutes of light >1000 lux) was reached in 46% of the days. Exposure > 1000 lux was lower during weekends than during weekdays.

Conclusion Older adults 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 older adults with ID, the current study suggests that environmental light exposure for this already frail population should be given more attention.

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 rhythm¹, a rhythm of about 24 hours apparent in most human physiological processes and behaviour. Examples of processes and behaviours with a circadian rhythm are the sleep-wake rhythm, mood and performance². The right amount of ocular light exposure and timing of the light exposure is essential for synchronization of the circadian rhythms. Insufficient ambient light or wrongly timed light exposure pushes the internal circadian rhythms out of sync with the external day-night rhythm, suggested to be associated with sleep- and mood complaints³.

In the general population, exposure to high illuminances is associated with positive affect⁴, less depressive symptoms^{5,6}, less sleep disturbances and overall better emotional well-being and quality of life⁷. People who were exposed to at least 30 minutes of illuminances above 1000 lux on a daily basis, experienced fewer depressive symptoms compared to people exposed to less illumination⁵. Elderly who were exposed to at least 50 minutes of light >1000 lux per day, slept more efficient⁸. Beneficial effects of light exposure on health are evidenced by the effect of bright light therapy in the treatment of mood and sleep problems^{9,10}.

In older adults with intellectual disabilities (ID) the prevalence of sleep problems is 72% (van de Wouw et al., 2013b), and the prevalence of depressive symptoms is 16.8% (van de Wouw et al., 2012, Hermans et al., 2013). Despite the growing knowledge about the effects of light exposure on sleep and mood, care organizations for people with ID are often poorly lit. Jelluma et al. (2012) compared the lighting in these care organizations 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 older adults with ID living in care facilities. In addition, we explore whether older adults with ID are exposed to light levels associated with better mood (30 minutes > 1000 lux daily) and sleep (50 minutes > 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 older adults with ID.

METHODS

Study setting and participants

The data presented here consist of data collected during two studies. The first study assessed the light exposure in older adults 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 older adults 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 – December 2017 were used.

Data of both studies were used to construct a dataset that follows a cross-sectional research design. The data were collected within three care organizations (Middin, ASVZ and SWZ) in collaboration with our department. The three care organizations 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 older adults 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, three of SWZ and one 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 for the first study were: (1) aged 50 years or older, (2) mild, moderate, severe or profound ID, (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 hour daily in the central living room, of which a minimum of 30 minutes between 07.00h and noon.

The Medical Ethical Committee of Erasmus Medical Center Rotterdam, the Netherlands 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 older adults with ID¹¹. The GeneActiv was not validated in older adults with ID, but was found to be valid and reliable in adults from the general population¹². Data from both accelerometers are well comparable¹³. 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 Toolbox¹³.

Three timeframes were defined; “Waking day” as the period between final wake time and sleep onset time. “Morning” as the four hours after wake time and “Evening” as the four hours 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-minute epochs. For reference; horizontal illuminance in a restaurant are 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 illuminances¹⁴, 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 Index¹⁵. The Barthel Index consists of ten items (for example: feeding, dressing, 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 good¹⁶⁻¹⁹.

Instrumental ADL were assessed with the Lawton index²⁰, consisting of eight items (for example: 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 adults²¹ and older adults with dementia²², it is considered a suitable instrument to use in older adults 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”²³.

Procedure

In the first study, participants were instructed to wear the light sensor and accelerometer for ten 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).

In case of overlapping participants in the two studies, data of the first measurement that provided raw light exposure data was included in this dataset. Following previous studies²⁴, only timeframes with <25% missing data were included in the present analyses to present the most representative and reliable data.

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 continuous variables, and chi-square tests for categorical variables. For participants with valid data, demographics and light exposure between the two studies were compared using independent T-tests for continuous variables, and chi-square tests for categorical variables.

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 (log lux) per timeframe (waking day, morning, evening) was calculated, possible differences between illuminance per timeframe was studied using a Oneway Anova. Log lux was transformed to lux for presentational purposes.

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 lux, 101-500 lux, 501-1000 lux and >1000lux) were summed. As data were not normally distributed, for each timeframe the median and interquartile range (IQR) of minutes spend in each category are presented.

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 Anova's were used for categorical outcomes level of ID and mobility. Analyses of light exposure and demographics during the waking day was corrected for duration of the waking day.

We calculated per participant the percentage of waking days that the threshold of 50 minutes >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 minutes 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.

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 were compared using One-way Independent Anova's. The amount of timeframes that met the prespecified thresholds related to sleep efficiency and depressive symptoms during the week and weekend were compared using Chi-square tests. Light exposure >1000 lux during the waking day over months were compared using multivariate general linear model (GLM), correcting for duration of the waking day. Light exposure >1000 lux for morning and evening over months were compared using general linear model (GLM).

RESULTS

Demographics and health status

Inclusion of participants and selection of data is shown in figure 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 ($t(77)=2.004, p=.049$).

Participants with data from the two studies did not differ based on age, sex, basic ADL and mobility (Supplementary table 4). Participants in the second study had a lower ability to perform instrumental ADL ($t(44)=-5.58206, p=.000$). Data on level of ID was 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, $p>.10$). 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, $p = .02$) and participants spend less time in >1000 lux during the morning (study 1; mdn 8 min, study 2; mdn 2 min, $p = .03$).

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 $22:01:15 \pm 01:12:49$, and final wake time was $8:09:53 \pm 01:16:23$. The duration of a waking day was on average $14:32:43$ hours $\pm 02:39:11$ hours.

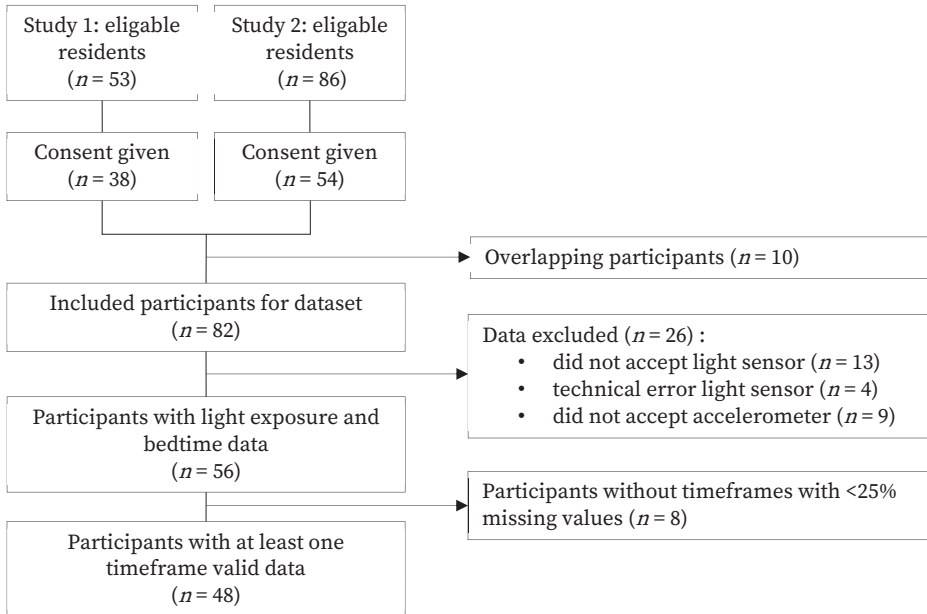


Figure 1. Flowchart inclusion of participants and selection of data.

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.

		overall	%	Participants with valid data	Participants without valid data	p ^a
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	.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			

* p < .05

^a independent t-test for continuous variables, chi-square test for categorical variables

None of the light exposure outcomes were associated with level of ID and (instrumental) activities of daily living. Participant who need support to be mobile, are exposed to 56 minutes less of light >1000 lux ($p=.025$) and 209 minutes more light of 501-1000 lux ($p=.000$) during the waking day, of which 62 min during the morning ($p=.000$), 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.

Light exposure in older adults with ID

Illuminance pattern

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

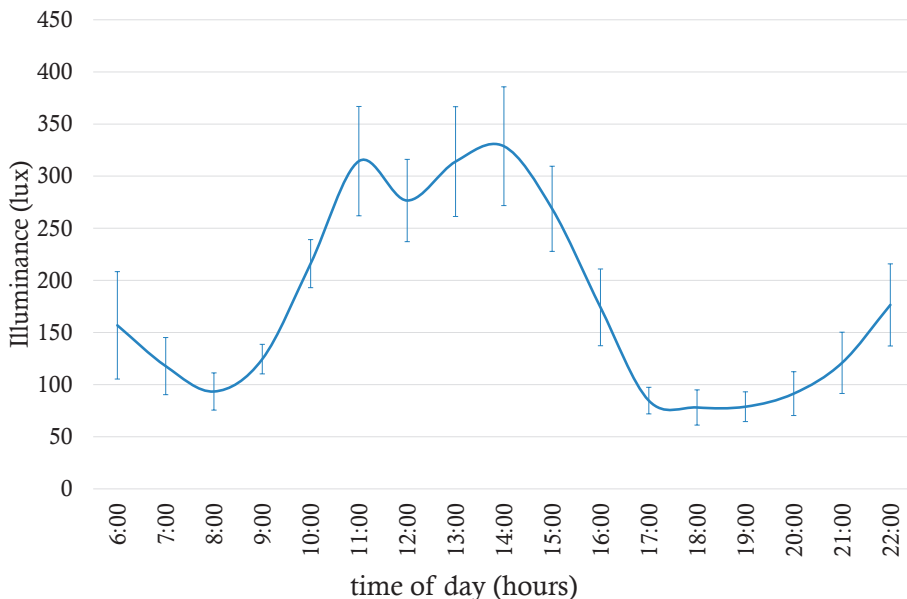


Figure 2. The personal illuminance pattern in lux of the waking day (06.00h -22.00h) of 33 participants of 115 waking days between October 2015 – April 2016 and October – December 2017.

Note. 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.

The plateau of illuminance was between 11.00h and 14.00h, after 14.00h the illuminance slowly decreased to a dip around dinner at 17.00h. After dinner time, the illuminance increased again up till 22.00h, which is explained by 6 participants with exposure to illuminance >200 lux after 21.00h.

Average illuminance during timeframes

The average illuminance during the waking day was 155 ± 1 lux (mean \pm SD). Post hoc analyses showed that average illuminance during the morning (166 ± 1 lux) was higher than during the evening (115 ± 1 lux) ($p=.006$).

Categorised illuminance during timeframes (Table 2)

During waking days, the median time spend in illuminances between 1-100 lux was 275 minutes (32%), followed by 274 minutes (32%) spend in 101-500 lux. The median time spend in >1000 lux during the waking day was 32 minutes (4%), of which 4.50 minutes during the morning. During the evening, participants spend a median of 94.50 minutes 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.

Exposure thresholds associated with sleep and mood (Table 3.)

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

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, ten participants did not reach the threshold on any of the days, the remaining 23 participants reached the threshold for 63% (range 11%-100%) of the days. Eight participants reached the threshold for mood every day.

Illuminance during week and months (Supplementary tables 5 and 6.)

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, $t(113)=2.962$, $p = .004$). 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; $mdn = 50$ minutes (5.6%), weekend; $mdn = 5.5$ minutes (.7%), $F(2)=6.43$, $p = .002$). During the weekend 18.5% of the waking days reached >50 minutes of light >1000 lux, compared to 50.6% during the week ($X^2(1, N = 115) = 11.01$, $p = .001$). During the

Table 2. 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.

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

weekend 28.9% of the waking days met the threshold of over 30 minutes of light >1000 lux, compared to 62.3% during the week ($X^2(1, N = 115) = 11.355, p = .001$).

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, $F(5) = 4.38, p = .001$). No differences in exposure to >1000 lux were seen for timeframes morning and evening.

Table 3. Exposure thresholds associated with sleep and mood for 33 participants with at least one valid waking day. Percentages of days that met thresholds within participants.

	Sleep (>50 minutes of >1000 lux per waking day)	Mood (>30 minutes 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%)

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 older adults 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 older adults 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 older adults from the general population this range during the waking day was 10 to 982 lux²⁵, indicating that the average illuminance during the day in older adults with ID is low.

The higher illuminances in the early morning and during the evening seen in some of the older adults 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 illuminance after 14.00h might be

because of the participants coming home from their daily activities were light exposure might have been higher.

Older adults with ID spent most of their waking day in indoor levels of light, which is comparable with the healthy general population of all ages^{5,26-28}. Participants were exposed to a median of 32 minutes of light >1000 lux. Average illuminances above 1000 lux in adults from the general population ranges between 58 and 105 minutes per waking day^{4,5,29-31}. Independently living elderly were exposed to 65 minutes³² to approximately 2 hours²⁵ of light levels above 1000 lux. Studies in clinical populations showed that patients with dementia in nursing homes were exposed for 10.5 minutes³³, and institutionalised elderly with schizophrenia 77 minutes a day to light >1000 lux³⁴. Older adults with ID living in group homes, like other groups in care facilities, were exposed to less light >1000 lux compared to the general population.

Older adults 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 exposure³⁵. Thus, bright light therapy as treatment for affective disorders is advised to be administered during the hours after waking up³⁶. Our results suggest that the timing of the exposure to light >1000 lux in older adults 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 older adults 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 older adults with ID are exposed to low levels of light >1000 lux, thresholds that might be associated with better sleep efficiency and mood.

Older adults 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, older adults 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 older adults 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 dataloggers showed that wearing the logger the wrong way around or underneath a coat, the data logger would record a tenth 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 before³⁷, 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 older adults with ID.

Aside from the missing data on light exposure, data on medical status was 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 lighting in the living environment could be formulated for specific populations of older adults 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^{38,39}. As the circadian rhythm is entrained under the influence of light with shorter wavelengths⁴⁰, measuring the spectral properties of light exposure would be advised too⁴¹. 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 older adults 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 older adults with ID living in group homes. Older adults 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 older adults with ID was timed in the afternoon. Overall, exposure in older adults 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, de Vink, Siebes (2012)⁴² are not counterbalanced by the personal daily light exposure of the older adults 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 older adults with ID, the current study suggests that environmental light exposure for this already frail population should be given more attention.

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SUPPLEMENTARY TABLES

Table 4. Participant characteristics of the participants with valid timeframes, comparison of participants from study one and study two with valid timeframes on demographics.

		Participants with valid data	Study 1	Study 2	p ^a
N		48	29	19	
Sex, n	female	29	16	13	.36
	male	19	13	6	
Age in years, mean (sd)		60.98 (9.16)	58.90 (9.28)	64.16 (8.23)	.051
Level of ID, n	Mild	9	4	5	.00*
	Moderate	13	2	11	
	Severe	0	0	0	
	Unknown	26	23	3	
Barthel score, mean (sd)		12.69 (6.31)	11.78 (5.94)	13.98 (6.76)	.25
Lawton score, mean (sd)		7.26 (6.31)	3.89 (5.66)	12.05 (5.66)	.00*
Mobility, n	independent	30	16	14	.57
	support	4	3	1	
	wheelchair	12	8	4	

* p < .05

^a independent t-test for continues variables, chi-square test for categorical variables,

Table 5. 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

Time frames	Minutes per timeframe	Average lux	1-100 lux					501 - 1000 lux					>1000 lux		Missing data
			Mean (SD)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	
Waking day ^a	77	886 (861-924)	2.24 (0.28)	260 (208-294)	291 (255-326)	87 (71-122)	50 (38-91)	137 (119-164)							
weekend	38	789 (763-833)*	2.07 (0.28)*	306 (254-348)	251.5 (219-292)	63.5 (17-82)	5.5 (2-13)*	134.5 (96-147)							
Morning ^b	102	240 (240-240)	2.22 (0.32)	76 (64-85)	83.5 (70-93)	15 (13-25)	8 (5-15)	24.5 (19-30)							
weekend	52	240 (240-240)	2.19 (0.34)	71.5 (58-97)	70 (64-93)	18.5 (13-38)	1 (0-6)	22.5 (11-31)							
Evening ^b	68	240 (240-240)	2.09 (0.52)	90.5 (61-117)	67 (50-84)	1 (0-8)	-	31 (27-40)							
weekend	28	240 (240-240)	1.97 (0.44)	114.5 (79-155)	39 (28-65)	-	-	26.5 (21-45)							

^a Multivariate general linear model (GLM), correcting for duration of the waking day^b One-way Independent Anova's. $p < 0.05$ *Week is reference, $p < 0.05$

Table 6. 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

Time frame	Month ^b	Time frames count	Minutes per timeframe		Average lux		1-100 lux		101-500 lux		501 - 1000 lux		>1000 lux ^c		Missing data	
			Median (IQR)	Mean (SD)	Minutes median (IQR)	Mean (SD)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)		
waking day	January	19	944 (811-989)	2.01 (0.28)	398 (312-513)	235 (150-325)	73 (15-228)	4 (0-11)	147 (99-191)							
	February	6	832.5 (808-878)	2.28 (0.19)	215 (121-299)	339.5 (291-344)	88 (77-115)	93 (43-100)	154 (119-199)							
	March	23	881 (848-966)	2.19 (0.29)	209 (189-297)	309 (261-422)	66 (60-93)	43 (22-107)*	166 (87-206)							
	April	2	974 (914-1034)	2.62 (0.13)	131 (101-161)	312 (267-357)	71.5 (38-105)	280.5 (274-287)	179 (137-221)							
	October	26	785 (745-836)	2.28 (0.24)	264.5 (225-323)	260.5 (175-292)	67 (64-148)	81.5 (42-115)*	102.5 (91-135)							
	November	23	825 (784-993)	2.15 (0.31)	273 (185-315)	235 (202-347)	85 (19-132)	26 (8-96)*	143 (110-164)							
	December	16	891.5 (810-921)	2.16 (0.27)	267.5 (212-329)	274.5 (219-315)	169.5 (23-236)	15.5 (2-43)	151.5 (60-183)							
morning	January	28	240 (240-240)	2.24 (0.36)	80.5 (65-103)	58 (35-70)	40.5 (11-60)	-	13 (5-24)							
	February	13	240 (240-240)	2.3 (0.23)	58 (48-79)	77 (64-113)	33 (7-50)	21 (9-43)	43 (30-52)							
	March	33	240 (240-240)	2.25 (0.26)	58 (45-76)	113 (92-125)	16 (15-34)	11 (3-23)	19 (15-25)							
	April	2	240 (240-240)	2.73 (0.55)	21.5 (0-43)	80 (0-160)	16 (8-24)	115.5 (15-216)	7 (0-14)							
	October	27	240 (240-240)	2.19 (0.39)	72 (64-142)	70 (66-97)	13 (7-29)	5 (2-34)	25 (11-34)							
	November	32	240 (240-240)	2.16 (0.31)	89.5 (59-104)	81 (65-103)	13.5 (6-27)	5 (1-14)	25.5 (13-40)							
	December	19	240 (240-240)	2.11 (0.31)	81 (55-122)	66 (54-93)	15 (0-60)	1 (0-6)	38 (23-48)							

Time frame	Month ^b	Time frames count	Minutes per timeframe		Average lux		1-100 lux		101-500 lux		501 - 1000 lux		>1000 Lux ^c		Missing data	
			Median (IQR)	Mean (SD)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)	Minutes median (IQR)		
Evening ^a	January	18	240 (240-240)	1.98 (0.46)	103.5 (60-158)	33.5 (17-88)	20 (0-68)	-	-	-	-	-	-	32.5 (23-44)	-	-
	February	8	240 (240-240)	1.99 (0.35)	90.5 (46-177)	112.5 (9-145)	-	-	-	-	-	-	-	29.5 (10-49)	-	-
	March	9	240 (240-240)	1.88 (0.29)	89 (83-218)	91 (1-149)	-	-	-	-	-	-	-	22 (16-52)	-	-
	April	1	240 (240-240)	2.36 (-)	-	209 (-)	-	-	-	-	-	-	-	31 (-)	-	-
	October	21	240 (240-240)	2.13 (0.47)	107 (64-125)	59 (32-82)	2 (1-15)	-	-	-	-	-	-	43 (20-51)	-	-
	November	17	240 (240-240)	2.22 (0.72)	37 (11-155)	52 (30-113)	1 (0-31)	2 (0-16)	-	-	-	-	-	45 (37-55)	-	-
	December	14	240 (240-240)	2.06 (0.49)	135.5 (23-177)	31 (19-43)	5.5 (0-105)	-	-	-	-	-	-	28 (21-49)	-	-

^a Month of measurement is unknown for 8 Evening timeframes

^b due to the low timeframes count, February and April were not included in the analyses

^c multivariate general linear model (GLM), analyses for timeframe waking day were corrected for duration of the waking day.

*January is reference, $p < 0.05$

5

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

Mylène N. Böhmer, Alyt Oppewal,
Marlies J. Valstar, Patrick J.E. Bindels,
Eus J.W. van Someren, Dederieke A.M. Festen

Submitted

6

Long-term effects of environmental dynamic light on sleep-wake rhythm and mood in older adults with intellectual disabilities

Mylène N. Böhmer, Alyt Oppewal, Patrick J.E. Bindels,
Eus J.W. van Someren, Dederieke A.M. Festen

Submitted

7

General Discussion

GENERAL DISCUSSION

Sleep problems are common in older people with intellectual disabilities (ID), but evidence based non-pharmacological interventions are limited. Sufficient light exposure is essential to regulate a healthy sleep-wake rhythm and mood, and increasing light exposure was shown to improve sleep and mood in populations without ID. The current dissertation focused on light exposure, sleep problems and mood, and studied the effect of increasing light exposure to improve sleep and mood in older adults with ID living in health care facilities. After a short overview of the principal findings of the studies presented in this dissertation, we will reflect on these findings and discuss future research and clinical recommendations.

Principal findings

First, we found that the sleep-wake rhythms of older adults with ID is less stable and more fragmented than that of older adults from the general population. The sleep duration of older adults with ID is longer and they lie awake longer after sleep onset. Sleep problems were overall more prevalent and severe in older adults with ID. We concluded that these differences in sleep-wake rhythms, prevalence and severity of sleep problems between older adults with and without ID are marked and possibly explained by medical, psychiatric conditions, care dependency, living in a care facility, environmental factors and lifestyle in older adults with ID.

Second, many studies have shown that light therapy is an effective treatment for both sleep problems and mood disorders in the general populations. However, little is known about the effect of habitual light exposure on sleep and mood in the general population. Therefore, we performed a systematic literature review on this topic, with a focus on personal light measurements. We found limited evidence for a positive relationship between the amount and timing of light exposure on the one hand and rest-activity rhythm and sleep architecture on the other hand. The evidence for an association between light exposure and timing of the circadian rhythm, sleep estimates, sleep quality, and mood is conflicting. We concluded that high quality intervention studies are needed to answer this question adequately.

Next up, we dove into the personal daily light exposure in older adults with ID. Previously it was found that care facilities for people with ID are often poorly lit. This can be compensated by light exposure outside the living environment. Therefore we studied personal light exposure during the waking day of older adults with ID, living in a care facility. We found that older adults with ID spent

most of their waking day in dim light (<500 lux) that varied little over the day. While early bright light exposure is preferred, most of the bright light exposure in our sample took place in the afternoon. We concluded that older adults with ID spend most of their days in low light levels that do not meet the proposed light levels associated with better sleep and mood.

All these projects led up to the intervention study in which we assessed the effect of environmental dynamic light in the common living area of care facilities for older adults with ID. We installed dynamic light in six group homes for people with ID, and measured sleep-wake rhythm, mood and behavior before and after installment. Even though we did not select our participants based on the presence of sleep problems, 57.1% of our study sample had at least one sleep problem. We did not find beneficial effects of increasing the environmental light intensity, neither on the sleep-wake rhythms, nor on sleep problems. However, light did have a large beneficial, and clinically relevant effect on depressive symptoms up to 14 weeks after installing the lights. We hypothesize that the organization of care and care dependency, for instance by the scheduled bed-times, might have limited the full range of effects of our intervention. Integrated dynamic lighting is a promising, undemanding and potentially effective addition to improve mood and behavior in care organizations for people with ID, but does not seem to do so by improving sleep or sleep-wake rhythms after 14 weeks.

Finally, as environmental dynamic light installations are a long-term investment, we studied the effects of dynamic light on sleep-wake rhythms and mood one year after installment. After one year, the total sleep time shortened and sleep onset time was later. These results should be interpreted with care, as we were unable to adequately monitor correct use of the light installation and possible changes in care prior to the long term measurements. We found no long term effect on mood or behavior. We had to conclude that as the study was not designed for the long term measurement, and therefore was underpowered. A high-quality study including a control group, for the long term effects, that take changes of seasons into account is necessary.

Reflection

Diagnosis of sleep problems in people with ID

Although the disturbances of sleep in ID are common, clear criteria to diagnose sleep problems in ID are lacking¹. A criterion for the diagnosis of sleep problems is whether the client experiences any burden from sleep problems. This requires the cognitive ability of self-reflection, which is often affected in people with ID. Therefore, the definitions or criteria for sleep problems as used in the general population might not apply to people with ID. As a result, different definitions

and criteria for sleep problems, e.g. insomnia, are used ¹. Clear definitions of sleep problems and corresponding cut-off values for objective sleep estimates in ID could help to improve the diagnosis of these problems.

Additionally, diagnosing sleep problems could be improved with the broad implementation of already available validated objective diagnostic instruments. Van de Wouw previously proposed that individual diagnosis of sleep and sleep-wake problems in older adults with ID should combine client and caregiver information with actigraphy ². Although research has shown that actigraphy is well applicable for people with ID, experience shows that broad implementation in practice stays behind. Additionally, our experience shows that care givers tend to underestimate the chance that their client will accept the actigraphy instrument. In the studies presented in this dissertation, we would just see whether participants would accept the instruments, this opposed to preliminary excluding participants who were known to lose or break actigraphy instruments ³. This meant that we repeatedly had to search for the instruments when we got to collect them, and we luckily often found them back (e.g. in knitting bags). The extra effort paid off as this strategy resulted in an acceptance rate of 83%, which is higher than the approximately 50% seen in a similar population before ³. Though testing feasibility of actigraphy in older adults with ID was not a part of the current study, our experience suggests that the acceptance rate might be higher than thought previously. Additionally, recently an algorithm was developed which allows to gain insight into sleep without the need for pressing the buttons to indicate bedtimes ⁴ and therefore making use of actigraphy even more applicable in ID settings.

Furthermore, in order to improve both diagnosis and treatment, guidelines on sleep problems in ID are needed. At the time of writing, multidisciplinary Dutch guidelines on sleep and sleep problems in long-term care are in the making ⁵. For these guidelines, scientific evidence on sleep in ID is systematically reviewed and weighted for the first time. Though, as mentioned before high quality research on interventions to improve sleep in ID is limited. So, in addition to these guidelines, more research on sleep problems is needed in order to provide caregivers with evidence-based tools to diagnose and treat sleep problems in ID.

Sleep wake-rhythm in care

We found that the sleep-wake rhythm in older adults with ID living in care facilities is affected by specific factors of this context. Caregivers assist residents by merely all activities during the day, including both the bedtime ritual as well as sleep-pressure inducing activities like walking ^{6,7}. Existing care schedules within care facilities do not always cater the personal preference of the residents for

instance by scheduled bedtimes, nor is it adjusted to the experienced sleep pressure, or tiredness, of the resident. As a result, caregivers report to experience the most restraints of freedom for the person with ID when it comes to sleep⁸. With regard to environmental factors that affect sleep, the living environments of people with ID are poorly lit during the day⁹, which is not counterbalanced by outdoor bright light (Chapter 4). We showed that older adults with ID are exposed to low light levels that are potentially insufficient to regulate the sleep-wake rhythm (Chapter 4). All in all, within the context of care facilities for people with ID an intertwined relationship exists between the organization of care and care dependency on the one hand, and the basic sleep hygiene to facilitate healthy sleep in older adults with ID on the other.

Basic sleep hygiene in care for older adults with ID provides a major leads for improvement. Sleep hygiene prescribes daytime behavior and bedtime rituals and includes aspects of environment that help to cater a good night of sleep. Sufficient physical activity and light exposure during the day, regularity in bedtimes, and dim light prior to bedtimes are suggested among others. Previous research showed that improving sleep hygiene by sleep scheduling, increasing daily activities or a combination does improve sleep in people with ID^{10,11}. As long as basic sleep hygiene criteria are not met, additional interventions to improve sleep might not reach their full potential.

Evidence supports the use of interventions approaching the multiple facets of the sleep-wake rhythm in favor to interventions that just target just one of them¹². This might well explain the lack of effect of the environmental dynamic light installations on the sleep-wake rhythm and prevalence of sleep problems from our study. With improving the environmental light exposure, we focused on a little piece of the puzzle to support healthy sleep in people with ID living in care facilities.

Mood and behavior in care for ID

Previous research showed that increased depressive symptoms are prevalent in 17% older adults with ID¹³, but often go unnoticed. Although depressive symptoms were no inclusion criteria for participation, on average 23% (range 17% - 29%) of the sample in our intervention study reported increased depressive symptoms at least once during baseline. Although we did not diagnose depression in our study, it is expected that a third of the people with increased depressive symptoms would meet the criteria for a major depressive episode¹³. The observed prevalence of increased depressive symptoms gives rise for screening for depression in ID. Therefore, implementation of regular screening for depressive symptoms using the well validated (Hamers et al., 2019, Hermans

et al., 2012) ADAMS screening list (Hermans et al., 2018, Rojahn et al., 2011) for depression and anxiety is suggested.

Conventional Bright Light therapy was recently shown to be a promising intervention for depression in adults with ID¹⁴. We showed that environmental dynamic light is effective in decreasing pre-clinical depressive symptoms after 14 weeks, as the prevalence of increased depressive symptoms in our study sample decreased from 23% to 9.8% (Chapter 5). In addition, we saw a decrease in irritability, lethargy and social avoidance which are also representing symptoms of depression in people with ID¹⁵. Although not a primary endpoint of our study, enhancing environmental light exposure might have preventive properties with regard to depression in people with ID.

Increasing environmental light exposure of people with ID

We focused on the relationship between light exposure, sleep and mood of older adults with ID. We showed that older adults with ID are exposed to light levels that are potentially insufficient to regulate the sleep-wake rhythm (Chapter 4). Improving environmental light exposure using dynamic light benefits mood and behaviour in older adults with ID living in group homes (Chapter 5).

Environmental dynamic light installations are a long-term investment that serves both the safe- and healthy living environment. When compared to conventional Bright Light Therapy, it is easier to implement, less time consuming and is thought to achieve greater compliance. The financial investment of the light installations we used in this projects were approximately 11.000 euros per living room. Ideally, a cost-efficacy analyses should proof whether this investment is worth it. Alternatively, given that lighting in care facilities for people with ID do not meet the requirements for visual functioning and safety at this point⁹, lighting could be improved to meet these requirements first, and whether this affects the sleep-wake rhythm and mood in people with ID could be evaluated. Though, given the current state of lighting in care facilities, we'd like to encourage to make the investment as enhancing environmental light exposure will inherently improve the current living environment for people with ID.

Aside from the financial investment, our experience showed that one should invest in instructing care givers and other users on the use of the installation too. Between the short (Chapter 5) and long term (Chapter 6) measurement, we did not monitor whether the installation was used properly. But there were instances where we arrived at the group home with the lights in dim light mode during the day, which might have interfered with a possible long-term effect. Instructions should especially impress upon the different needs for lighting for the older eye,

as what might be judged as safe and comfortable by a younger eye, might not align with what is needed for the older one.

With the increasing interest in the health effects of light in the living environment, care organizations for people with ID ask for a guideline regarding this issue. Recommendations for lighting in hospitals and nursing homes are available¹⁶. These guidelines are not integrated in care for people with ID, as illustrated by the low light levels in the living environment⁹. Furthermore, existing guidelines focus on lighting to serve the visual system, and do not take into account the properties of light needed to regulate the sleep-wake rhythm. We propose to implement the existing recommendations for lighting for nursing homes¹⁶ as long as specific guidelines for older adults with ID that include recommendations for light properties to serve the sleep-wake rhythm are not available.

Measuring light exposure and light properties

Over the last years, studies on light as treatment for numerous conditions took a flight. However, personal light exposure prior, during and after the interventions was not measured. We acknowledge that measuring personal light exposure can be challenging. Despite the fact that measuring personal light exposure was shown to be feasible in our population before¹⁷, the measurements resulted in a lot of missing data due to erroneous use of the light sensor. This 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^{18,19}. As the circadian rhythm is entrained under the influence of light with shorter wavelengths²⁰, measuring the spectral properties (e.g. wavelengths or colour temperature) of light exposure would be advised too²¹. By properly measuring light exposure and its properties, we might gain more insight in the relationship between light and sleep-wake rhythm and mood in day-to-day life.

Both research as well as practice calls for identification of daily dose of light exposure and its properties needed to entrain the circadian rhythm to the natural day-night cycle²². The properties of the most effective dynamic light installation are unknown. A recent review showed that environmental dynamic light comes in all shapes and sizes, where some are effective and others are not²³. To identify effective properties of light installations, guidelines were published that describe how to report on used light interventions by describing the specific properties of light that affect the circadian rhythm²⁴. This requires additional measurements of the spectral properties of the dynamic light installations. Unfortunately, we did not perform these measurements in our intervention study, and were therefore not able to follow these guidelines in reporting on the used

dynamic light. By following these guidelines in future research, the therapeutic effect of dynamic light could be specified.

Scientific research in care for people with ID

With the transition from “what works” to “whats works best”, care for people with intellectual disabilities calls for high quality scientific research on evidence-based care. Academic Collaboration Centers for people with ID are composed, where care organizations for people with ID work together in conducting and implementing scientific research. Facilitating factors to successfully perform scientific research are, among others, broad support throughout all layers of the organization^{25,26}. The study conducted for this dissertation was situated in a care facility that had no previous experience with scientific research. By establishing a close collaboration with all parties within the care organization from a very early stage and throughout all stages of the project, we achieved broad support for the project which resulted in the successful completion of the project.

Despite the need for scientific research in care for people with ID, it has to battle an image problem. Limiting beliefs about scientific research in care organizations for people with ID are; it takes a lot of time and money, and it is hardly possible to conduct research within this “challenging population”. As a result, conventional scientific methods are prematurely deemed to be non-applicable in this population, and creative alternative research methods are introduced. Given our experience, we’d like to challenge existing limiting beliefs and want to advocate to not discard conventional research methods. Especially for health-related topics, objective quantitative methods are unbearable in order to identify, prevent and treat health conditions in order to increase the quality of care for people with ID. Qualitative and alternative research methods could be used in addition, not as a substitute. If the right conditions are met, high quality scientific research is also possible within the care for people with ID.

With regard to funding of research in ID, the focus of subsidizers of research has been heavy on participation, collaboration and implementation. Ideally, this focus would not affect the scientific quality of the subsidized grant proposal. Unfortunately, anecdotal evidence suggests that a grant proposal can be turned down when considered to be “too academic”. Therefore we’d like to support the current tendency to consult both professional expertise as well as scientific expertise to formulate the research agenda, and to formulate concrete steps to implement the retrieved knowledge to improve the care in an early stage of the proposal. But we’d like to advocate that this should not be at the expense of the quality and thoroughness of the scientific research itself, which is, after all, conditional for actual sound knowledge and eventual improvement of care.

Future research

Future research should use high quality methods to study etiology, definitions, measuring- and treatment of sleep problems in people with ID. With regard to measuring light exposure, focus could be on studying reliable and applicable instruments to measure light in challenging populations. Second, these instruments should measure properties of light that affect the circadian clock, such as spectral properties of light. Furthermore, the relationship between light exposure, disrupted sleep-wake rhythms and sleep problems on daily functioning, behavior, mood, frailty and mortality could be studied to identify the impact of these problems on daily life and health of people with ID.

As mentioned before, so far few evidence-based interventions for sleep problems in people with ID are available. At the time of writing, just one ongoing trial on sleep in this population was registered. So, when it comes to light as treatment for sleep-wake rhythm and mood in ID, a randomized controlled trial on both the preventative properties, both on short term as well as long-term effects of light on sleep and mood, is needed. Additionally, a randomized controlled trial on groups with known sleep-, mood or behavioral problems would be of interest. Light exposure prior- and during the intervention should be adequately measured and the most effective properties of the light installations should be identified.

Finally, in our intervention study on dynamic light, professional caregivers reported on mood and behavior 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 behavior of the participants. Therefore, future studies should take the effect of the dynamic light on the professional caregivers into account.

Recommendations for clinical practice

Based on the previous, we can formulate recommendations for clinical practice. The first step in better detection of sleep problems is formulating clear definitions for sleep problems and broad implementation of readily available objective diagnostic instruments, such as actigraphy. Next, preconditions for healthy sleep should be met, to start with sleep hygiene and improving the environmental light exposure. An additional step will be the proper implementation of upcoming guidelines for diagnoses and treatment of sleep problems in people with ID.

Although not the primary focus of our study, though prompted by the prevalence of increased depressive symptoms in our sample, we would like to emphasize the importance of regular screening on depressive symptoms using the ADAMS²⁷ to battle the underdiagnoses of depression in older adults with ID.

More attention could be given to the living environment to support older adults with ID. In this dissertation we focused on environmental light exposure for people with ID, but others studied the auditory environment in care facilities for ID²⁸. The impact of environmental factors such as lighting and the auditory environment, the ambiance, but also access to the outdoors and safety on well-being could not be overstated. One anecdote that stayed with me; one participant really liked to do crafts. Because of her bad vision, she used a magnifier lamp to crochet. When I met her at the first baseline measurement of the intervention study, she told me that the lamp in the magnifier in her room broke. I reported this to the facility, but the lamp was not fixed during the 30 weeks of our study. Which meant that she struggled to crochet, which made it tiresome and made her not to enjoy it as much. Sometimes it are the small things that brighten the day.

Concluding remarks

The current dissertation adds to the knowledge on prevalence and severity of sleep problems in people with ID. Additionally, we identified low light exposure as possible cause for these problems. We provided knowledge on the effect of environmental dynamic light on sleep-wake rhythm and mood in people with ID. These light installations are effective in improving mood within 14 weeks, but we did not find an effect on the sleep-wake rhythm. Organization of current care for persons with ID plays an important role. This supports the principle that healthy sleep is multidimensional issue and needs a multidimensional approach. We suggest that preconditions for healthy sleep in care for people with ID should gain more attention, and evidence-based interventions to improve the sleep-wake rhythms and mood in older adults with ID are needed.

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8

Summary
Samenvatting

SUMMARY

Chapter 1 General Introduction

Good sleep is important to stay healthy, especially for frail populations like older adults with intellectual disabilities (ID). In the current dissertation we focused on light, sleep and mood in older adults with ID living in care facilities.

Previously, a large cohort study on healthy aging in older adults (>50 years) with ID (the Healthy Ageing and Intellectual Disabilities study; HA-ID study) showed that 72% of the study population had at least one sleep problem. Common sleep problems were settling problems, short sleep, maintaining sleep during the night and waking early. These sleep problems were associated with poor health outcomes, such as challenging behavior and mood problems. It was hypothesized that regulation of the sleep-wake rhythm, being a complex brain function, might be affected in people with ID, increasing their risk for sleep problems.

The sleep-wake rhythm follows a circadian rhythm, a rhythm that displays an oscillation of about 24 hours. These 24-hour rhythms are driven by a circadian clock which lies in the suprachiasmatic nucleus (SCN) in the hypothalamus of the midbrain. Although always present, the rhythms are adjusted to the natural light-dark cycle by external cues called Zeitgebers (German for “time-givers”), of which (day)light is the strongest. Insufficient or badly timed light exposure is related to disrupted circadian rhythm, and is related to sleep problems and mood complaints.

Increasing light exposure by using light therapy is shown to be effective in improving mood and sleep in both the general population, as well as hospitalized populations. Limited evidence is available on the beneficial effect of increasing light exposure in people with ID and sleep and mood. Previously it was shown that the living environment of older adults with ID is poorly lit. As light is the most important ‘Zeitgeber’ for the circadian rhythm, enhancing light exposure in the living environment for older adults with ID might be a promising tool to improve their sleep-wake rhythm and mood.

Given 1) the high prevalence sleep problems in older adults with ID, and 2) the suboptimal lighting conditions in the living environment of people with ID and 3) the beneficial effect of light therapy on sleep and mood in other populations, the aim of the current dissertation was to study the relationship between light exposure, sleep and mood in older adults with ID living in a care facility. We describe the personal daily light exposure of older adults with ID and we evaluated the effect of improving the lighting in care facilities on the sleep-wake rhythm and mood in older adults with ID. This dissertation is the result of the

collaboration between Middin, a Dutch care provider for people with intellectual disabilities and the research group of Intellectual Disability Medicine of Erasmus Medical Center Rotterdam, the Netherlands.

Chapter 2 Sleep problems in older adults with ID

Sleep problems are common in people with ID. In the general population sleep changes with aging, and sleep problems become more prevalent with aging. It is unknown how sleep problems in older adults with ID compare to the sleep problems seen in older adults of the general population. Therefore, we compared objectively measured sleep-wake rhythms and the prevalence and severity of sleep problems of older adults with ID to that of older adults from a large representative sample from the general population.

Actigraphy data of 501 older adults with ID from the Healthy Ageing and Intellectual Disabilities study was compared to the data of 1734 older adults from the general population from the Rotterdam Study. We found that the sleep-wake rhythms of older adults with ID was less stable and more fragmented than those of older adults from the general population. Older adults with ID had a longer sleep duration than older adults from the general population, and lay awake longer after sleep onset. With regard to sleep problems, we found that these are more prevalent and more severe in older adults with ID, when compared with older adults from the general population. These results remain after correction for differences in age, sexe, Body mass index (BMI) and daily functioning.

We concluded that the differences in prevalence and severity of sleep problems between older adults with and without ID are not just the result of aging as seen in older adults from the general population. Medical, psychiatric conditions and lifestyle in older adults with ID living in a care facility are marked as possible explanations for the found differences. Better understanding of sleep and associated factors in older adults with ID is needed to improve the quality of sleep in this population.

Chapter 3 Review on the relationship between light exposure, sleep and mood

Insufficient light exposure is assumed to be related to sleep problems and mood complaints. Though, most studies are conducted within a controlled laboratory setting, or in populations in extreme situations like shift workers. Few studies focus on the role of whole-day light exposure in the habitual setting in the development of these health problems. Therefore, we conducted a systematic literature review to describe the association between personal light exposure in

the habitual setting and sleep-wake rhythm, and mood in healthy adults from the general population.

Studies were included if they assessed light exposure directly on the participants for at least one full day and reported both individual personal light exposure and outcomes sleep and/or mood.

Twenty-five papers were eventually included in this review. All included studies were cross-sectional, and individual light exposure was usually measured with a wrist-worn device. The overall quality of the included studies was considered low because of the lack of intervention studies and unreliable light exposure measurements.

Given the low quality of the included studies, the review only provided a first exploration on the association between light exposure and sleep-wake rhythm and mood in healthy adults from the general population. We found limited evidence that higher light intensity and earlier timing of light exposure is beneficial for the synchronization of the sleep-wake rhythm with the day-night rhythm, the stability of the sleep-wake rhythm and sleep architecture. We found conflicting evidence for the relationship between intensity and timing of light exposure and the timing of sleep-wake rhythm (circadian phase), sleep and mood. Data from intervention studies are needed to gain insight into the causal mechanism of the relationship between light exposure and sleep-wake rhythm and mood.

Chapter 4 Light exposure in older adults with ID

Light exposure is important for the regulation of the sleep-wake rhythm and mood. Sleep problems and mood complaints are common in older adults with ID living in care facilities. Previously it was found that care facilities of older adults with ID are often poorly lit, which is hypothesized to contribute to the high prevalence of sleep problems and mood complaints. In this chapter we described the personal light exposure pattern during the waking day in older adults with ID, and study whether light exposure meets the proposed threshold for sleep efficiency and good mood.

In this study, 82 older adults with ID living in 16 residential homes of three care organizations (Middin, ASVZ and SWZ) in the Netherlands wore a light sensor for 7 days. We found that older adults with ID spend most of their waking day in dim light environment (<500 lux) and little over 30 minutes per day in bright light (>1000 lux). Half of our sample met the thresholds for light exposure associated with better sleep and mood most of the days.

Given the importance of adequate light exposure for regulation of sleep and mood, and the prevalence of sleep and mood problems in older adults with ID,

this study suggests that environmental light exposure for this already frail population should be given more attention.

Chapter 5 Short-term effects of dynamic lighting on sleep and mood in older adults with ID

Evidence-based interventions to improve the sleep-wake rhythm, mood, and behavior in older adults with ID are limited. Increasing light exposure has been shown to be effective in improving the sleep-wake rhythm, mood, and behavior in other populations. In this chapter, we studied the effect of installing environmental dynamic lighting in common living rooms of group homes on sleep-wake rhythm, mood, and behavior in older adults with ID.

We installed environmental dynamic lighting in six group homes and included fifty-four participants in our study. Prior to installing the lighting, we measured the sleep-wake rhythm, mood and behavior three times (week 1, 4 and 9). After installing dynamic light, we measured these again during weeks 3, 7 and 14 after installing light. The sleep-wake rhythm was measured using actigraphy. Questionnaires on mood and behavior of participants were filled out by the professional care givers.

We found no effect of dynamic lighting on the sleep-wake rhythm of older adults with ID. After installing light we observed that sleep onset time advanced, and depressive symptoms decreased. For behavior we saw an improvement in hyperactivity, lethargy and irritability. We did not observe any adverse effects.

We concluded that installing dynamic lighting in common living areas for older adults with ID improved the mood and behavior of the residents up to 14 weeks after placement. The current organization of care and care dependency of our population might explain the lack of effect of light on the sleep-wake rhythm. Bedtimes are often scheduled to set times, and residents are often assisted with getting in- and out of bed. Integrated dynamic lighting is a promising, undemanding and potentially effective tool to improve mood and behavior in care organizations for people with ID, but does not seem to do so by improving sleep or sleep-wake rhythms.

Chapter 6 Long-term effects of dynamic lighting on sleep and mood in older adults with ID

Environmental dynamic lighting is a long-term investment. Therefore, 45 participants of the short-term study also took part in the study that investigated the long-term effect (after one year) of the environmental dynamic light installations in the common living rooms of six group homes on sleep-wake rhythm, mood and behavior in older adults with ID.

When compared to baseline measurements, we did not find a long-term change of stability or other outcomes of the sleep-wake rhythm one year after installing dynamic light. We did find sleep duration to shorten with 25 minutes and a 25 minute delay in sleep onset time. One year after light installation mood and behavior did not change.

We found no evidence for a long-term effect of environmental dynamic lighting on sleep-wake rhythm, mood and behavior in older adults with ID living in care facilities. Nor did we find a change in the prevalence of sleep problems, but we did find an effect for total sleep duration and sleep time. The clinical significance of these results is unclear. Furthermore, these results should be interpreted with caution as we cannot rule out that changes at the group homes between the short-term and long-term measurements might have influenced the results. Care may have changed or dynamic lighting may have been used incorrectly. Also, the current study had a limited number of participants. The need for more research on long term effects of enhancing environmental light in ID settings is evident.

Chapter 7 General discussion

The current thesis explored the relationship between light exposure, sleep and mood in older adults with ID living in a care facility. We found that sleep problems are more prevalent and more severe in older adults with ID, when compared to older adults from the general population. Light exposure in older adults with ID is low and possibly insufficient to regulate the sleep-wake rhythm and mood.

Although sleep problems or mood complaints were not a prerequisite to participate in our intervention study on the effect of dynamic light on sleep and mood, we found that 57% of our sample had a sleep problem at baseline, and 23% of our sample scored for increased depressive symptoms at baseline. Improving the living environment with dynamic light installations is effective in improving mood of older adults with ID, but did not affect sleep-wake rhythm and sleep problems. Sleep, mood and behaviour did not change one year after installing the light. The current organization of care and care dependency of our population might explain the lack of effect of light on the sleep-wake rhythm.

Taking the methodological limitations into account, we formulated recommendations for clinical practice. The first step in better detection of sleep problems is broad implementation of readily available objective diagnostic instruments, such as actigraphy. Second, as current diagnostics for sleep problems rely on subjective self-report of the client, which is challenging in ID, we advised to formulate objective definitions for sleep problems in ID. Given the high prevalence of depressive symptoms in our sample, we advised to regularly

screen for depressive symptoms. Next, preconditions for healthy sleep should be met, to start with sleep hygiene and improving lighting in the living environment and implementing upcoming guidelines for diagnosing and treatment of sleep problems in people with ID.

With regard to scientific research, we advised to use high quality methods to study etiology, definitions and treatment of sleep problems in people with ID. Furthermore, the relationship between light exposure, disrupted sleep-wake rhythm and sleep problems and the effect of this relationship on daily functioning, behavior, mood and important (health)outcomes like frailty and mortality could be studied to identify the impact of these problems on daily life and health of people with ID. So, when it comes to light as treatment for sleep-wake rhythm and mood in ID, randomized control trials on both the preventative properties, as well as the long-term effects of light on sleep and mood are needed.

We suggested that preconditions for healthy sleep and lighting in care for people with ID should gain more attention, and we concluded that evidence-based interventions to improve the sleep-wake rhythms and mood in older adults with ID are needed.

SAMENVATTING

Hoofdstuk 1 Algemene inleiding

Goed slapen is heel belangrijk voor een goede gezondheid. Slaap problemen komen veel voor bij ouderen met een verstandelijke beperking (VB) die in een zorginstelling wonen. Uit een groot onderzoek naar de gezondheid van ouderen (≥ 50 jaar) met een VB, het GOUD-onderzoek (Gezond Ouder worden met een VB), bleek dat 72% van de ouderen met een VB tenminste één slaapprobleem heeft. Dit zijn problemen met inslapen, doorslapen, kort slapen en vroeg wakker worden. Deze slaapproblemen worden gerelateerd aan gezondheidsklachten, en in het bijzonder stemmings- en gedragsproblemen.

Verstoorde slaap kan gezien worden als verstoring van het slaap-waakritme. Dit slaap-waakritme volgt een circadiaan ritme, een ritme van ongeveer 24 uur dat wordt gereguleerd door de biologische klok in het brein. Elke dag wordt het interne ritme afgestemd met het externe dag-nacht ritme. Daglicht is het sterkste signaal om het ritme te synchroniseren. Onvoldoende licht of lichtblootstelling op het verkeerde moment zorgt ervoor dat het circadiaan ritme niet synchroon loopt met het externe dag-nachtritme. Er zijn aanwijzingen dat onvoldoende licht of lichtblootstelling op het verkeerde moment slaapproblemen en stemmingsproblemen kunnen veroorzaken. In dit proefschrift hebben we ons gericht op de rol van licht in het reguleren van een gezond slaap-waak ritme bij ouderen met een VB die in een zorginstelling wonen.

Met de toenemende kennis over het belang van licht voor gezonde slaap en goede stemming, wordt lichttherapie steeds vaker ingezet als behandeling voor slaapproblemen en stemmingsklachten. Bij conventionele lichttherapie zitten mensen elke ochtend van de therapie 30 minuten achter een lichtlamp. Lichttherapie is effectief gebleken in het verbeteren van slaap en stemming in de algemene bevolking en in verschillende klinische populaties zoals mensen met dementie. Onderzoek naar lichttherapie bij mensen met een VB staat nog in de kinderschoenen. Er zijn aanwijzingen dat lichttherapie de slaap en stemming kan verbeteren van mensen met een VB.

Ondanks de kennis over het belang van licht voor slaap en stemming, zijn woningen voor mensen met een VB vaak slecht verlicht. Uit eerder onderzoek bleek dat de verlichtingssterkte op woningen en dagactiviteitencentra voor mensen met een VB, in 93.3 % van de gevallen niet voldoet aan de ARBO-norm. Dit gaf aanknopingspunten voor het verbeteren van de leefomgeving door het installeren van dynamische verlichting, en het evalueren van het effect van deze verlichting op het slaap-waakritme, de stemming en het gedrag bij ouderen met een VB.

Gezien 1) de hoge prevalentie van slaapproblemen bij ouderen met een VB, en 2) de gebrekkige verlichting van woningen voor mensen met een VB en 3) de effectiviteit van lichttherapie op slaap en stemming bij andere populaties, beschrijft dit proefschrift de relatie tussen persoonlijke lichtblootstelling, slaap en stemming bij ouderen met een verstandelijke beperking. We onderzochten de persoonlijke lichtblootstelling van ouderen met een VB en onderzochten het effect van het verbeteren van omgevingsverlichting op slaap en stemming van ouderen met een VB die in een zorginstelling wonen. Dit proefschrift is resultaat van een samenwerking tussen leerstoel Geneeskunde voor Verstandelijke Beperking van het Erasmus Medisch Centrum, Rotterdam en Middin (Rijswijk, Zuid-Holland), een zorginstelling voor mensen met een VB.

Hoofdstuk 2 Slaapproblemen van ouderen met een VB

Slaapproblemen komen vaak voor bij mensen met een VB. In de algemene populatie zien we dat de slaap verandert met de leeftijd en dat mensen naar mate ze ouder worden ook meer slaapproblemen hebben. We weten niet hoe slaapproblemen bij ouderen met een VB zich verhouden tot de slaapproblemen die worden gezien bij ouderen uit de algemene bevolking. Daarom hebben we in dit hoofdstuk de slaap en de prevalentie en ernst van slaapproblemen van ouderen met een VB vergeleken met die van ouderen uit de algemene bevolking.

Objectieve slaapdata, gemeten door middel van actigrafie (Actiwatch: een pols gedragen activiteit meter), van 501 ouderen met een VB (≥ 50 jaar; GOUD-onderzoek) werden vergeleken met de slaapdata van 1734 ouderen uit de algemene bevolking (≥ 45 jaar, ERGO-onderzoek). Het slaap-waakritme van ouderen met een VB was minder stabiel en meer gefragmenteerd dan dat van ouderen uit de algemene bevolking. Ouderen met een VB hadden een langere slaapduur dan ouderen uit de algemene bevolking, en hadden meer moeite met doorslapen. We vonden dat slaapproblemen meer voorkomen, én ernstiger zijn bij ouderen met een VB dan bij ouderen uit de algemene bevolking. Deze resultaten bleven bestaan nadat we hadden gecorrigeerd voor een verschil in leeftijd, geslacht, gewicht, en dagelijks functioneren.

We concludeerden dat de prevalentie en ernst van slaapproblemen van ouderen met een VB niet alléén verklaard wordt door veroudering. Als mogelijke verklaringen worden onder anderen de medische, psychiatrische aandoeningen en levensstijl van deze populatie genoemd. Een beter begrip van het slaap-waakritme van ouderen met een VB en geassocieerde factoren is nodig om de slaapkwiteit van deze populatie te verbeteren.

Hoofdstuk 3 Literatuuronderzoek naar de relatie tussen licht, slaap en stemming

Uit eerder onderzoek weten we dat onvoldoende lichtblootstelling kan leiden tot slaap problemen en stemmingsklachten. Deze onderzoeken vinden vaak plaats in een laboratorium, of bij mensen in extreme omstandigheden, bijvoorbeeld mensen die ploegendiensten werken. Er is echter weinig bekend over de relatie tussen lichtblootstelling, slaap en stemming in het dagelijks leven van mensen uit de algemene populatie. Daarom hebben we in dit hoofdstuk een systematische review van de literatuur uitgevoerd waarin we de relatie beschrijven tussen persoonlijke lichtblootstelling in het dagelijks leven en slaap-waakritme en stemming bij gezonde volwassenen uit de algemene bevolking.

Hiervoor hebben we een zoekopdracht opgesteld waarmee we verschillende databases met wetenschappelijke artikelen hebben doorzocht. Artikelen werden geselecteerd als de persoonlijke lichtblootstelling werd gemeten en zowel de persoonlijke lichtblootstelling als de slaap en/of stemming gerapporteerd worden in het artikel.

Uiteindelijk zijn er 25 artikelen geselecteerd. In alle onderzoeken werden deelnemers eenmaal gemeten (cross-sectioneel onderzoek). Lichtblootstelling werd meestal gemeten met een lichtsensoren op de pols, hoewel is dit niet vreselijk betrouwbaar is gebleken. Dit in combinatie met het gebrek aan interventie-onderzoek, leidde ertoe dat kwaliteit van de geïncludeerde onderzoeken als laag werd beoordeeld.

Gegeven de lage kwaliteit van de beschikbare onderzoeken, kan slechts een eerste verkenning weergegeven worden van de relatie tussen lichtblootstelling, slaap en stemming in het dagelijks leven van volwassenen uit de algemene bevolking. We vonden beperkt bewijs dat hogere lichtintensiteit en een vroegere timing van lichtblootstelling gunstig is voor het synchroniseren van slaap-waakritme met het dag-nacht ritme, de stabiliteit van het slaap-waakritme en hoe nachtelijke slaap is opgebouwd (slaaparchitectuur). We vonden tegenstrijdige bevindingen voor de relatie tussen intensiteit en timing van lichtblootstelling en de timing van het slaap-waakritme (circadiane fase), slaap en stemming. Er zijn interventiestudies nodig om inzicht te krijgen in het causale mechanisme van de relatie tussen lichtblootstelling, slaap-waakritme en stemming.

Hoofdstuk 4 Lichtblootstelling van ouderen met een VB

Voldoende lichtblootstelling is belangrijk voor het reguleren van het slaap-waakritme en de stemming. Slaapproblemen en stemmingsklachten komen veel voor bij ouderen met een VB die in zorginstellingen wonen. Eerder werd vastgesteld dat zorginstellingen van ouderen met een VB vaak slecht verlicht zijn.

Dit draagt mogelijk bij aan de hoge prevalentie van de slaapproblemen en stemmingsklachten in deze populatie. In dit hoofdstuk beschrijven we persoonlijke lichtblootstelling bij ouderen met een VB. Ook onderzoeken we of ouderen met een VB aan voldoende licht worden blootgesteld voor optimale slaapefficiëntie en een goede stemming.

We vroegen 82 ouderen met een VB van 16 woningen van drie Nederlandse zorgorganisaties (Middin, SWZ en ASVZ), om zeven dagen een ketting met een lichtsensor te dragen. De resultaten laten zien dat ouderen met een VB het grootste deel van hun dag doorbrengen in een lichtintensiteit die zich laat beschrijven als sfeerlicht. Ouderen met een VB worden iets meer dan 30 minuten per dag blootgesteld aan een lichtintensiteit die vergelijkbaar is met daglicht. De helft van de bewoners voldeed aan de aanbevolen hoeveelheid lichtblootstelling die gerelateerd is met goede slaap en een goed stemming.

Gegeven het belang van voldoende lichtblootstelling voor het reguleren van slaap en stemming, en de prevalentie van slaap- en stemmingsproblemen bij ouderen met een VB, benadrukken de resultaten van dit onderzoek dat de lichtblootstelling van ouderen met een VB meer aandacht zou moeten krijgen.

Hoofdstuk 5 Het korte termijn effect van dynamische verlichting op slaap en stemming bij een VB

Op dit moment is er een beperkt aanbod van bewezen effectieve interventies voor slaapproblemen en depressieve klachten van ouderen met een VB. Zowel conventionele lichttherapie als lichtinstallaties in de leefomgeving zijn wel effectief gebleken in het verbeteren van het slaap-waakritme, de stemming en het gedrag bij andere populaties. In dit hoofdstuk onderzochten we het effect van dynamische verlichting op woningen voor ouderen met een VB op slaap-waakritme, stemming en gedrag.

We plaatsten dynamische verlichting aan de plafonds van de gemeenschappelijke leefruimtes van zes woningen voor ouderen met een VB. Vierenvijftig deelnemers deden mee aan ons onderzoek. Voordat de verlichting werd geïnstalleerd, werd driemaal (week 1, 4 en 9) het slaap-waakritme, de stemming en het gedrag van de deelnemers gemeten. Na het installeren van de verlichting werd dit opnieuw driemaal gemeten, te weten 3, 7 en 14 weken na installatie. Het slaap-waakritme werd gemeten door middel van actigrafie (GENEActiv: een pols gedragen activiteit meter). Vragenlijsten over de stemming en het gedrag van de deelnemers werden ingevuld door de persoonlijk begeleider van de deelnemers.

Het slaap-waakritme van ouderen met een VB verbeterde niet nadat de verlichting was geïnstalleerd. Wel vonden we dat bewoners eerder in slaap vielen en dat depressieve symptomen afnamen. Tot slot vonden we dat hyperactiviteit,

lethargie en prikkelbaarheid afnamen. Er werden geen bijwerkingen van de verlichting gerapporteerd.

We concludeerden dat de dynamische verlichting tot 14 weken na plaatsing een positief effect had op de stemming en het gedrag van ouderen met een VB. Mogelijke verklaringen voor het gebrek aan effect van licht op het slaap-waakritme is hoe de zorg op dit moment is georganiseerd en de zorgafhankelijkheid van de populatie. Zo hebben bewoners vaak vaste bedtijden en wordt een deel van hen geholpen bij het in- en uit bed komen. Dit laat weinig ruimte voor de persoonlijke voorkeuren van de bewoners. Dynamische verlichting is een veelbelovend, makkelijke en potentieel effectieve manier om de stemming en het gedrag van mensen met een VB te verbeteren, maar lijkt dit niet te doen door het slaap-waakritme te verbeteren.

Hoofdstuk 6 Het lange termijn effect van dynamische verlichting op slaap en stemming bij een VB

Dynamische verlichting is een lange termijn investering. Daarom hebben we in dit hoofdstuk het lange-termijn effect (na één jaar), van dynamische verlichting op slaap en stemming van ouderen met een VB onderzocht.

We hebben de deelnemers van de korte-termijn studie opnieuw uitgenodigd om deel te nemen aan de lange-termijn meting. Uiteindelijk deden 45 deelnemers mee aan de lange-termijn meting. Alle deelnemers hebben opnieuw een week lang de GENEActiv gedragen waarmee we het slaap-waak ritme hebben gemeten. Vragenlijsten over stemming en het gedrag van de deelnemers werden opnieuw ingevuld door de persoonlijk begeleiders.

Een jaar na de installatie van de dynamisch verlichting was het slaap-waak ritme niet veranderd ten opzichte van voor het installeren van de verlichting. Wel vonden we dat bewoners gemiddeld 25 minuten later in slaap vielen en dat de slaapduur 25 minuten korter was. Een jaar na installatie vonden we geen verandering in stemming en het gedrag.

We concludeerden dat een jaar na installatie geen effect was gevonden van dynamische verlichting op het slaap-waakritme, de stemming en het gedrag bij ouderen met een VB die in zorginstellingen wonen. We vonden geen verandering in prevalentie van slaapproblemen, maar vonden wel een effect voor totale slaapduur en inslaaptijd. De klinische betekenis van deze resultaten zijn onduidelijk en dit effect moet voorzichtig geïnterpreteerd worden. We kunnen niet uitsluiten dat veranderingen op de woningen tussen de korte-termijn en lange-termijn metingen hebben de resultaten hebben beïnvloed. Mogelijk is de zorg veranderd of is de dynamische verlichting onjuist gebruikt. Ook had het lang-termijn onderzoek een beperkt aantal deelnemers. Er is behoefte aan meer

onderzoek naar lange-termijn effecten van het verbeteren van de verlichting in de leefomgeving van mensen met een VB.

Hoofdstuk 7 Algemene discussie

Dit proefschrift beschrijft de relatie tussen lichtblootstelling, slaap en stemming bij ouderen met een VB die in een zorginstelling wonen. We vonden dat, in vergelijking met ouderen uit de algemene bevolking, slaapproblemen vaker voorkomen en ernstiger zijn bij ouderen met een VB. Lichtblootstelling van ouderen met een VB is laag en mogelijk onvoldoende om het slaap-waakritme en de stemming te reguleren. Ondanks dat slaap problemen of stemmingsklachten geen voorwaarde waren om deel te nemen aan onze interventiestudie naar het effect van licht op slaap en stemming, vonden we dat voor het plaatsen van de verlichting 57% van ons sample een slaapprobleem had, en 23% scoorde voor verhoogde depressieve klachten. Het verbeteren van de verlichte omgeving door middel van dynamische lichtinstallaties is effectief in het verbeteren van de stemming van ouderen met een VB, maar heeft geen effect op het slaap-waakritme of slaapproblemen. Slaap en stemming veranderden tot aan een jaar na installatie van verlichting niet. Mogelijke verklaringen voor het gebrek aan effect van licht op het slaap-waakritme is hoe de zorg op dit moment is georganiseerd en de zorgafhankelijkheid van de populatie.

Op basis van deze resultaten en de ervaringen opgedaan tijdens het onderzoek, geven we in dit hoofdstuk de volgende aanbevelingen voor de klinische praktijk: de eerste stap voor betere signalering van slaapproblemen is brede implementatie van reeds beschikbare objectieve instrumenten voor het meten van slaap, zoals actigrafie. Ten tweede, voor het diagnosticeren van slaapproblemen in de algemene populatie is de eigen ervaring leidend, deze zijn in VB veelal moeilijk te verkrijgen. Daarom adviseren wij om objectieve definities voor slaapproblemen bij mensen met een VB te formuleren. Gegeven de hoge prevalentie van verhoogde depressieve symptomen bij mensen met een VB, raden we aan om hier regelmatig op te screenen. Ook verdienen de randvoorwaarden voor een gezonde slaap meer aandacht, te beginnen met slaaphygiëne, het verbeteren van de verlichte omgeving en het implementeren van aankomende richtlijnen voor diagnose en behandeling van slaapproblemen bij mensen met een VB.

Voor wetenschappelijk onderzoek adviseerden we om de etiologie, definitie- en behandeling van slaapproblemen bij mensen met een VB te prioriteren. De relatie tussen lichtblootstelling, slaap-waakritme en slaapproblemen en het effect van deze relatie op dagelijks functioneren, gedrag, stemming, maar ook belangrijke (gezondheids)maten als kwetsbaarheid en sterfte kunnen verder worden onderzocht. Zo krijgen we meer inzicht in de impact van deze problemen

op het dagelijks leven en de gezondheid van mensen met een VB. Ook adviseren we om gerandomiseerde onderzoeken met controlegroepen uit te voeren naar de preventieve- en lange-termijn effecten van dynamische verlichting als behandeling van slaapproblemen en depressieve klachten bij mensen met een VB.

Tot slot adviseerden we meer aandacht te hebben voor de randvoorwaarden voor een gezonde slaap en de verlichte omgeving van mensen met een VB, en om evidence-based interventies te ontwikkelen om het slaap-waakritme en de stemming bij ouderen met een VB te verbeteren.

9

Curriculum Vitae
PhD Portfolio
Publications
Dankwoord

CURRICULUM VITAE

Mylène Nathalie Böhmer werd op zondag 2 maart 1986 geboren in Rotterdam. Na in 2004 te zakken voor het eindexamen, haalt zij in 2005 haar VWO diploma op het Sint Stanislas College in Delft.

Tijdens haar studie Psychologie aan de Universiteit van Amsterdam, werd Mylène's interesse voor wetenschappelijk onderzoek aangewakkerd en verder ontwikkeld tijdens een uitgebreide onderzoeksstage bij de Kinderen Bipolaire Ouders-studie van de afdeling Psychiatrie van het Universitair Medisch Centrum Utrecht. Zij deed ook klinische ervaring op tijdens een stage bij Sophia Revalidatie Gouda. In 2011 behaalde zij haar master Klinische Neuropsychologie.



Na haar afstuderen fietste Mylène een maand lang Ierland rond. Daarna werkte zij korte tijd in de thuiszorg en waarna zij in april 2012 start als onderzoeksassistent bij het Nederlands Studiecentrum Criminaliteit en Rechtshandhaving (NSCR). Daar assisteert Mylène bij onderzoek naar de voorspellers van behandeluitkomst van een cognitieve vaardigheden training bij gedetineerden. Daartoe reist zij 2,5 jaar door Nederland om in gevangenissen gedetineerden te interviewen en neuropsychologische taken bij hen af te nemen.

In 2015 startte Mylène als promovendus bij Middin en de leerstoel Geneeskunde voor Verstandelijk Gehandicapten van het Erasmus Medisch Centrum, waar zij het Bright-onderzoek uitvoerde. In 2018 ontvangt zij samen met Middin een subsidie van het Zorgondersteuningsfonds om het Bright-onderzoek uit te breiden. Tijdens haar promotietraject houdt Mylène zich doorlopend bezig met wetenschapscommunicatie, zo is zij commissielid van het Wetenschapscafé Rotterdam en stond zij in het theater als spreker bij de Science Battle. Ook volbracht zij in 2019 Female Talent Class, een programma voor getalenteerde vrouwen aan het begin van hun wetenschappelijke carrière.

Sinds 2021 werkt zij als senior onderzoeker bij PsyQ Kenniscentrum ADHD bij volwassenen en ouderen. Daar doet zij onder anderen onderzoek naar het verbeteren van slaap van volwassenen met ADHD en begeleidt zij promovendi.

Mylène woont in Rotterdam. Zij heeft vele (corona-)hobby's uitgeprobeerd. Op het moment van schrijven bekijken slechts; de wereld rond fietsen, koken en bakken, en lezen over normale mensen met een bijzonder leven.

Mylène Nathalie Böhmer was born on Sunday 2 March 1986 in Rotterdam, the Netherlands. After failing her final exams in 2004, she finished her pre-university education in 2005 at Sint Stanislas College in Delft, the Netherlands.

During her study Psychology at the University of Amsterdam, Mylène's interest in scientific research is sparked and developed further with an extensive research internship at the Dutch Bipolar Offspring study at the Department of Psychiatry of the University Medical Center Utrecht. Additionally, she gains clinical experience with an internship at Sophia Rehabilitation Gouda. In 2011 she obtained her master's degree in Clinical Neuropsychology.

After graduating, Mylène cycled through Ireland for a month. In April 2012 she started working as a research assistant at the Netherlands Institute for the Study of Crime and Law Enforcement (NSCR). Here, Mylène assists in research into the predictors of treatment outcome of cognitive skills training among detainees. For 2,5 years, she visited prisons throughout the Netherlands to interview detainees in prisons and to perform neuropsychological assessments.

In 2015, Mylène started as a PhD-student at Middin, a care organization, and the chair of Intellectual Disability Medicine at the Erasmus Medical Center Rotterdam, where she conducted the Bright-study. In 2018 she, in collaboration with Middin received a grant from the Zorgondersteuningsfonds to expand the Bright-study. Throughout her PhD trajectory, Mylène was involved in science communication. She was a committee member of the Science Café Rotterdam and performed as a speaker at the Science Battle. In 2019 she completed Female Talent Class, a program for talented women at the start of their scientific career.

Since 2021 she is a senior researcher at PsyQ Expertisecenter Adult ADHD. Her research topics are sleep and treatment of sleep in adult ADHD.

Mylène lives in Rotterdam. She has tried many (lockdown)hobbies, to date only the following stuck; cycling around the world, cooking and baking, and reading about normal people with extraordinary lives.

PHD PORTFOLIO

Name PhD student: Mylène Nathalie Böhmer
 Erasmus MC Department: Intellectual Disability Medicine,
 Department of General Practice

Research School: NIHES

Promotors: Prof. dr. P.J.E. Bindels
 Prof. dr. E.J.W. van Someren

Supervisors: Dr. D.A.M. Maes- Festen
 Dr. A. Oppewal

PhD Period: January 2015 – December 2021

Date thesis defense: 01 June 2022

	Year(s)	EC
General Courses		
Systematic Review in Pubmed and other databases - Medical library, Erasmus MC	2015	1.00
English Writing - Erasmus University	2015	2.00
Patient Oriented Research – Consultatiecentrum voor Patiëntgebonden Onderzoek, Erasmus MC	2016	0.30
Training Limesurvey – Erasmus MC	2017	1.00
Basiscursus Pregelgeving Klinisch Onderzoek (Brok) - NFU	2017	1.50
Scientific Integrity – Erasmus MC	2017	1.00
Repeated Measurements – NIHES, Erasmus MC	2018	1.70
Missing Values in Clinical Research – NIHES, Erasmus MC	2018	1.70
Multilevel Analyse – Epidm, VU Amsterdam	2018	2.00
Lectures and Workshops		
Sleep in Intellectual Disabilities – Specialist training of physicians for people with Intellectual Disabilities, Erasmus MC (lecture)	2015, 2016, 2017	3.00
Lighting for sleep and mood in people with Intellectual Disabilities – Middin, care organization (workshop)	2016 – 2018	2.00
Scientific research in people with Intellectual Disabilities – Middin, care organization (workshop)	2017, 2019	1.00
Presentations		
Presenting at Department of General Practice, Erasmus MC	2015 - 2020	2.00
Presenting at teams and departments Middin, care organization	2015 - 2020	1.00
National and international conferences		
World Conference - International Association for the Scientific Study of Intellectual and Developmental Disabilities (IASSIDD) (oral/poster; Melbourne, Glasgow)	2016, 2019	2.00

Annual Meeting - Society for Light Treatment and Biological Rhythms (SLTBR) (oral/poster; Berlin, Groningen, Chicago)	2017, 2018, 2019	3.00
Slaap congres – Nederlandse vereniging voor Slaap-Waak onderzoek (NSWO) (attendance)	2016, 2017	1.00
Focus op Kennis en Onderzoek – Kennisplein Gehandicaptenzorg (oral, Utrecht, Ede)	2015, 2018	2.00
Supervising		
Medical student master theses (2 x) – Intellectual Disability Medicine, department of General Practice, Erasmus MC	2017, 2018	2.00
Critical reading – Department General Practice, Erasmus MC	2015-2019	1.00
Other		
Female Talent Class – Erasmus MC	2019	2.00
Organizing and attending Science Café Rotterdam	2016 - 2018	2.00
Speaker at Science Battle	2017 - 2019	1.00
Total EC		37.20

PUBLICATIONS

This thesis

Böhmer, M. N., Oppewal, A., Bindels, P. J. E., Tiemeier, H., van Someren, E. J. W., & Festen, D. A. M. (2020). Comparison of sleep-wake rhythms in elderly persons with intellectual disabilities and the general population. *Sleep Medicine*, 76, 148-154. <https://doi.org/10.1016/j.sleep.2020.10.019>

Böhmer, M. N., Hamers, P. C. M., Bindels, P. J. E., Oppewal, A., van Someren, E. J. W., & Festen, D. A. M. (2021). Are we still in the dark? A systematic review on personal daily light exposure, sleep-wake rhythm, and mood in healthy adults from the general population. *Sleep Health*. <https://doi.org/10.1016/j.sleh.2021.06.001>

Böhmer, M. N., Valstar, M. J., Aarts, M. P. J., Bindels, P. J. E., Oppewal, A., van Someren, E. J. W., & Festen, D. A. M. (2021). Shedding light on light exposure in elderly with intellectual disabilities. *Journal of Intellectual Disability Research*. <https://doi.org/10.1111/jir.12822>

Böhmer, M. N., Oppewal, A., Valstar, M. J., Bindels, P. J. E., van Someren, E. J. W., & Festen, D. A. M. Light up: an intervention study of the effect of environmental dynamic lighting on sleep-wake rhythm and mood in older adults with intellectual disabilities. *Journal of Intellectual Disability Research*. (submitted)

Böhmer, M. N., Oppewal, A., Valstar, M. J., Bindels, P. J. E., van Someren, E. J. W., & Festen, D. A. M. Long term effect of environmental dynamic lighting on sleep-wake rhythm and mood in older adults with intellectual disabilities. *Journal of Intellectual Disability Research*. (submitted)

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van Duijnhoven, J., Aarts, M. P., Aries, M. B., **Böhmer, M. N.**, & Rosemann, A. L. (2017). Recommendations for measuring non-image-forming effects of light: A practical method to apply on cognitive impaired and unaffected participants. *Technology and Health Care*, 25(2), 171-186. <https://doi.org/10.3233/thc-161258>

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Tijdschrift voor Artsen voor Verstandelijk Gehandicapten, 4, 48-51. https://nvavg.nl/wp-content/uploads/2018/01/TAVG-2017-04_website.pdf

Böhmer, M. N., Oppewal, A, Valstar, M. J., Aarts M. P. J., Bindels, P. J. E., & Maes - Festen, D. A. M. (2021). Slaapproblemen in de spotlights. Slaapproblemen en het belang van voldoende lichtblootstelling bij mensen met een verstandelijke beperking. *Tijdschrift voor Artsen voor Verstandelijk Gehandicapten*, 4, 214-217. https://nvavg.nl/wp-content/uploads/2021/12/Art_Bohmer_Magazine_NVAVG_NR_4.pdf

DANKWOORD

Ik zou willen stellen dat het succesvol afronden van een promotie sterk samen hangt (minstens $r > .80$, $p < .01$) met de kwaliteit van de mensen om je heen. De volgende mensen hebben dit voor mij mogelijk gemaakt.

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Slaapproblemen komen veel voor bij ouderen met een verstandelijke beperking die in een zorginstelling wonen. Deze slaapproblemen worden gerelateerd aan gezondheidsklachten, en in het bijzonder stemmings- en gedragsproblemen. Het aanbod aan wetenschappelijk bewezen interventies voor slaapproblemen van deze doelgroep is beperkt. Lichttherapie is in de algemene populatie en verschillende klinische populaties, zoals ouderen met dementie, een effectieve behandeling gebleken voor slaapproblemen en stemmingsklachten.

Dit proefschrift beschrijft de relatie tussen licht, slaap en stemming van ouderen met een verstandelijke beperking die in een zorginstelling wonen. Er wordt toegewerkt naar de interventiestudie waarin wordt onderzocht of dynamische verlichting in de leefomgeving effectief is in het verminderen van slaapproblemen en stemmingsklachten van ouderen met een verstandelijke beperking.

Op basis van de resultaten van het onderzoek worden aanbevelingen gedaan voor het leveren van zorg rondom slaap en stemming van ouderen met een verstandelijke beperking, en hoe verlichting in de leefomgeving deze zorg kan ondersteunen.