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REVIEW ARTICLE

Light therapy in insomnia disorder: A systematic review and meta-analysis

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Summary

In the management of insomnia, physicians and patients are seeking alternative therapeutics to sleeping pills, in addition to sleep hygiene and cognitive behavioural therapy. Bright light therapy (LT) has proven its efficacy in circadian and mood disorders. We conducted a systematic literature review and meta-analysis according to Cochrane and PRISMA guidelines and using the databases Medline, Cochrane, and Web of Science, with a special focus on light therapy and insomnia. Twenty-two studies with a total of 685 participants were included, five of which with a high level of proof. Meta-analysis was performed with 13 of them: light therapy for insomnia compared with control conditions significantly improved wake after sleep onset (WASO: SMD = −0.61 [−1.11, −0.11]; $p = 0.017$; weighted difference of 11.2 min ±11.5 based on actigraphy, and SMD = −1.09 [−1.43, −0.74] ($p < 0.001$) weighted difference of −36.4 min ±15.05) based on sleep diary, but no other sleep measures such as sleep latency, total sleep time (TST), or sleep efficiency. Qualitative analysis of the review showed some improvement mainly in subjective measures. Morning light exposure advanced sleep–wake rhythms and evening exposure led to a delay. No worsening was observed in objective nor subjective measures, except for TST in one study with evening exposure. A light dose–response may exist but the studies' heterogeneity and publication bias limit the interpretation. To conclude, light therapy shows some effectiveness for sleep maintenance in insomnia disorders, but further research is needed to refine the light parameters to be chosen according to the type of insomnia, in the hope of developing personalised therapeutics.

KEYWORDS

bright light therapy, chronobiology, insomnia, meta-analysis, phototherapy, sleep disorder

1 | INTRODUCTION

Insomnia affects 30% to 50% of the adult population (Chan-Chee et al., 2011), and the prevalence of chronic insomnia is estimated to be between 5% and 7%, depending on studies, countries, and classifications applied (Chan-Chee et al., 2011; Ohayon, 2002). Insomnia disorder is one of the ten most frequent consulting motives in general practice and is a societal and economic burden and therefore is a public health concern (Letrillart et al., 2014).

Currently, there is no "ideal sleeping pill" (Touitou, 2007). The most commonly used hypnotic molecules are the "z-drugs", for example zolpidem and zopiclone, which efficiently induce sleep but fail to maintain it

because of their short half-life (Rosenberg, 2006). As observed with benzodiazepines, they have important side effects, including falls in the elderly, memory difficulties, daytime somnolence, drug habituation, and dependency with withdrawal syndrome (Gunja, 2013), or even major misuse (Casati et al., 2012). Hypnotics represent a short-term solution, but are nevertheless regularly used as a long-term treatment. Their consumption and side effects increase with age (Briot, 2006). This has led health authorities to limit access to these drugs by reducing the reimbursement and by controlling the prescription of zolpidem in France for instance.

There is a consensus among academic societies to favour non-pharmacological approaches for chronic insomnia, including sleep hygiene measures and cognitive behavioural therapy (CBT-I) (Riemann et al., 2017; Riemann & Perlis, 2009). While their efficiency has been proven, implementing them in everyday practice remains difficult. Indeed, far too few practitioners are trained and able to manage patients with these methods, which, moreover, remain time-consuming for both practitioners and patients (Davidson et al., 2019; Lasserre et al., 2010). Therapeutic alternatives are therefore still being sought, and bright light therapy (LT) could be one of them.

Indeed, light influences sleep and alertness in different ways, indirectly through clock synchronisation and phase shifting of circadian rhythms, and directly through an alerting effect independent of the biological clock. Light is also known to affect cognitive functions and mood and has been suggested to influence the sleep homeostat (Hubbard et al., 2013; Maruani and Geoffroy, 2022; Tsai et al., 2009).

Over the past three decades we have seen a growing interest in light effects on behaviour and their use as a therapy for addressing insomnia symptoms, although evidence remains inconclusive regarding insomnia disorder. In 2016 a meta-analysis reviewed the effects of light therapy on sleep problems in general, reporting an effect on insomnia symptoms and fatigue (Maanen et al., 2016), especially with higher light dosage. Given the complex role of light on sleep and waking, these encouraging results raise several questions. Can we determine the parameters of light administration that will be most effective in improving insomnia symptoms, taking into account light intensity, duration and time of administration, and wavelength composition? Considering the heterogeneity of insomnia disorders (Palagini et al., 2022), is there any type of insomnia that is more responsive to light therapy? Indeed, although well-defined bright light therapy (LT) protocols have been established for circadian rhythm sleep–wake disorders (Figueiro, 2016) or seasonal (Meesters et al., 2011) and non-seasonal depression (Geoffroy et al., 2019; Tuunainen et al., 2004), light therapy protocols for insomnia remain to be defined.

Therefore, we conducted a systematic review and meta-analysis of randomised controlled-trials, aiming to evaluate the overall effect of light therapy on insomnia disorder, but also taking into account for the first time the subtype of insomnia and parameters of treatment, in order to identify the light parameters (time of day, intensity, duration, spectrum) to be chosen according to the type of insomnia.

2 | METHOD

A systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Moher et al., 2009) guidelines for articles that measured the efficacy of light therapy on subjective and objective sleep parameters, and according to the Cochrane handbook (Higgins & Green, 2011).

The literature search was performed using PubMed, Web of Sciences, and Cochrane library databases with no publication date restrictions and until 31 October 2022.

Keywords equations for the three databases are shown in the appendix. Duplicates were removed using Zotero. Potentially eligible articles were reviewed based on title and abstract (JC, JM, EF). After screening, the selected studies were reviewed based on the full text according to inclusion and exclusion criteria by three authors (JC, JM, EF). If they did not agree on the inclusion or exclusion for some of the studies, two other researchers were consulted to reach a consensus (PAG and PB).

The search on PubMed used the following keywords equation: ("light therapy"[tiab] OR "light treatment"[tiab] OR "phototherapy"[tiab]) AND ("insomnia"[tiab] OR "chronic insomnia disorder"[tiab] OR "chronic insomnia"[tiab] OR "insomnia disorder"[tiab] OR "primary insomnia"[tiab] OR "sleep disorder"[tiab] OR "sleep disturbance"[tiab] OR "sleep quality"[tiab] OR "sleep alteration"[tiab]). The search on Cochrane used the following keywords equation: "light therapy" OR "light treatment" OR "phototherapy" in title abstract keyword AND "insomnia" OR "chronic insomnia disorder" OR "insomnia disorder" OR "Sleep disorder" in title abstract keyword - (word variations have been searched). The search on Web of Science used the following keywords equation: (ALL = ("light therapy") OR ALL = ("light treatment") OR ALL = ("phototherapy")) AND (ALL = ("insomnia") OR ALL = ("chronic insomnia disorder") OR ALL = ("insomnia disorder") OR ALL = ("Sleep Disorder") OR ALL = ("Sleep"))

2.1 | Study selection

2.1.1 | Eligibility criteria

Studies were included in the present literature review according to the following criteria:

Criterion A: must have enrolled only patients who had been diagnosed with chronic insomnia disorder. We also included studies in which insomnia diagnosis was not based on proper classification criteria, but was based on "sleep troubles" including at least one insomnia complaint, without any other diagnosis of sleep disorder.

Criterion B: studies assessing the efficacy of light therapy.

Criterion C: publication written in English.

And for the meta-analysis:

Criterion D: Study design had to be a randomised controlled trial (RCT) with intervention and control arms. Eligible control conditions were placebo light condition, crossover, sleep hygiene, and CBT-I, but for the latter only if the active light conditions also had sleep hygiene or CBT-I. *This criterion was used only for the quantitative systematic review (meta-analysis). For the qualitative systematic review, study designs other than RCT were also included.*

Criterion E: if the trial administered light therapy as adjunctive to another intervention (such CBT-I), the other intervention had to be

equally administered in both intervention and control arms to be able to rule out the effect of the adjunct treatment.

2.1.2 | Exclusion criteria

We defined exclusion criteria for the eligible studies to be retained in the analyses, which were the following:

- Lack of validated subjective assessments (e.g., sleep records, self-report of sleep on the Pittsburgh sleep quality index, etc) and/or objectives measures of sleep disturbance (actigraphy, polysomnography (PSG), or nocturnal electroencephalography (EEG))
- Studies not reporting on a light therapy intended to improve sleep complaints (at least one sleep outcome had to be reported, even if this was a secondary objective)
- Participants of the study were under 18 years old
- Individuals with insomnia disorder associated with seasonal affective disorder or neurodegenerative comorbidity
- Studies not reporting on a light intervention aimed at improving sleep complaints (at least one sleep outcome had to be reported, even if this was a secondary objective) such as light therapy for depression
- Studies reporting on circadian rhythm sleep–wake disorders were excluded

2.2 | Data extraction and reporting

2.2.1 | Data collection process

Three reviewers (JC, EF, JM) independently extracted data from the published articles and from their supplementary materials if available.

2.2.2 | Data items

Light therapy description

For each study we described the time of administration, the daily and total duration of the intervention and the intensity of light exposure. When specified, light colour spectrum or any detailed light specifications were also collected. Intensity and duration of light therapy sessions varied from one study to another. In order to move towards the standardisation of light parameters (Lucas et al., 2014), and to make them comparable, we multiplied the dose and the exposure duration (in hours), resulting in a unit of lux per hour (lux-h). For example, the calculated dose was 5000 lux-h for a session at 10,000 lux for 30 min or for a session at 2500 lux for 2 h.

Outcome data

Objective data extracted from polysomnography or actimetry were sleep onset latency (SOL), total sleep time (TST), time in bed (TIB), sleep efficiency (SE), wake after sleep onset (WASO). Subjective data were extracted from the sleep diary and were the same as above. In addition, information from standardised questionnaires were systematically collected such as sleep quality (e.g. insomnia severity index (Bastien et al., 2001)), sleepiness/alertness, mood, cognitive performance, and quality of life.

2.3 | Risk of bias for individual studies

The risk of bias for individual studies was assessed using the Cochrane collaboration's tool for assessing risk of bias in randomised trials (Higgins et al., 2011). To avoid inter-rater discrepancies (Hartling et al., 2012), our evaluation was completed using tools from the SIGN handbook for assessing the quality of evidence (Scottish Intercollegiate Guidelines Network (SIGN), 2015), including the number of participants, the comparison, the relevance for our target population, funding sources. We synthesised the quality of proof of each study in three gradations: weak, intermediate, and high. Of note, the estimated risk of bias does not necessarily reflect the overall quality of the included studies since they were evaluated according to the present study inclusion criteria and measures of interest.

2.4 | Data synthesis

First, we made a quantitative analysis of the data by conducting a meta-analysis of studies when at least three studies reported the same objective sleep assessment. The mean duration along with standard deviations (SD) was used in the calculation of the standardised mean difference (SMD) and 95% confidence interval (95% CI). For each outcome, we conducted a meta-analysis comparing the post-intervention mean between the LT group and the control group. To avoid the assumption that all studies are estimating the same treatment effect, a random effects meta-analysis was conducted. The residual heterogeneity was assessed using the restricted maximum likelihood method. The I^2 statistic was used to quantify heterogeneity between studies, with values of 25%, 50%, and 75% reflecting a small, medium, and large degree of heterogeneity, respectively.

Selective reporting was evaluated within each study by investigating discrepancies between the described measures and the reported association in the results and publication bias was assessed by visual inspection of funnel plots (asymmetries suggesting potential publication bias) and Egger's regression test for funnel plot asymmetry. This initial synthesis was completed with a qualitative approach, with a general synthesis of the results, as well as a stratified synthesis by typology of the insomnia disorder and by the time of administration of light therapy.

3 | RESULTS

3.1 | Studies description

The search in electronic databases yielded 296 results (after exclusion of duplicates), from which we excluded 225 articles based on title and

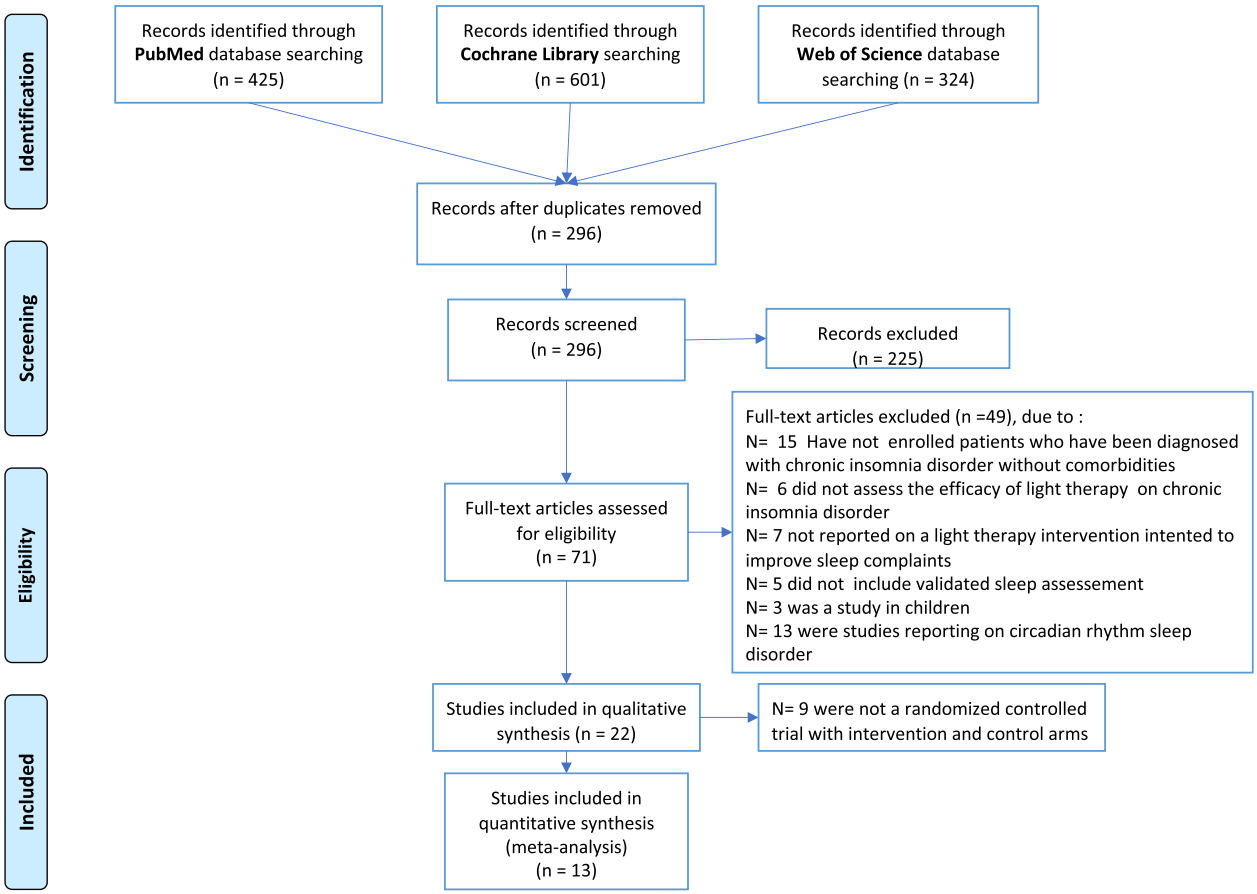

FIGURE 1 Flow chart of study selection process [Color figure can be viewed at wileyonlinelibrary.com]

abstract. We evaluated 71 articles in detail and we excluded 49 of them based on our eligibility criteria. Hence, A total of 22 studies were included in the review (Akyar & Akdemir, 2013; Altena et al., 2008; Burkhalter et al., 2015; Campbell et al., 1993; Campbell & Dawson, 1991; Cooke et al., 1998; Dekker et al., 2020; Friedman et al., 2009; Friedman et al., 2012; Garland et al., 2018; Guilleminault et al., 1995; Johnson et al., 2016; Kirisoglu & Guilleminault, 2004; Lack et al., 1994; Lack et al., 2005; Lack & Wright, 1993; Lack & Wright, 2007; Lederle et al., 2010; Münch et al., 2011; Murphy & Campbell, 1996; Pallesen et al., 2005; Suhner et al., 2002; Youngstedt et al., 2005; Zeitzer et al., 2011) and 13 of them provided the necessary data to perform a meta-analysis (Figure 1).

We evaluated seven studies as low, 10 as intermediate, and five as high level of proof (Table 1).

The 22 studies involved 726 participants, of which 442 had light therapy. The mean age was 64.2 years old with a mean of 63% of women. The mean number of participants in each study was 33 (SD 24.7), with a mean of 20 in the LT group (SD 12.7).

A total of 15 of them were parallel-group RCT, three of the oldest studies were non-randomised CT, one was a crossover RCT and three were before–after studies. The light placebo condition was dim red light in 11 studies, with an intensity between 40 lux to 400 lux. Other comparison groups were diverse: waitlist, physical activity, melatonin, doxepin, blue versus white light, afternoon vs evening LT, and 20 versus 45 min of LT.

A majority of the studies chose a light intensity higher than 2000 lux-h (19/22), two of the three studies with lower intensity chose a blue-enriched bright white light, considering them as effective as higher doses of white light (Table 2).

3.2 | Meta-analyses of light therapy and sleep measures

3.2.1 | Sleep latency

There were no significant differences in the outcome of the objective measure of sleep latency between the control and LT treated group, with a SMD of −0.29 [−1.22, 0.64] ($p = 0.32$) (I^2 87%, funnel plot asymmetry $p < 0.001$) corresponding to a weighted difference of −5.5 min (SD 5.05 min) (Figure 2a). No significant differences were observed when only studies examining morning exposure were considered.

There were also no significant differences in subjective measures of SL (SMD = −0.85 [−1.84, 0.15], $p = 0.58$, $I^2 = 77.9\%$), corresponding to a weighted difference of −8.6 min (SD 6.84) (Figure 2b).

TABLE 1 Level of proof synthesis. [Color table can be viewed at wileyonlinelibrary.com]

	Study type	Random sequence generation	Allocation concealment	Blinding of participants and researchers	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias	Eligibility for review	Overall level of proof
Akyar 2013	Before–after	×	×	×	×	✓	?	×	Yes	Weak
Altena 2008	RCT	✓	?	?	?	✓	✓	✓	Yes	Intermediate
Burkhalter 2014	RCT	✓	✓	?	×	✓	✓	✓	Yes	High
Campbell 1991	CT	?	?	×	×	?	?	?	Yes	Weak
Campbell 1993	CT	✓	?	?	?	✓	✓	✓	Yes	Intermediate
Cooke 1998	Before–after	×	×	×	×	✓	✓	×	Yes	Weak
Dekker 2021	RCT	✓	✓	✓	?	✓	✓	✓	Yes	High
Friedman 2009, Zeitzer 2011	RCT	✓	✓	✓	?	✓	✓	✓	Yes	High
Friedman 2012	RCT	✓	✓	✓	?	✓	✓	✓	Partial	Intermediate
Garland 2018, Johnson 2016	RCT	✓	✓	✓	?	?	?	?	Partial	Intermediate
Guilleminault 1995	RCT	✓	✓	×	×	✓	✓	?	Yes	Intermediate
Kirisoglu 2004	RCT	✓	?	?	?	✓	?	?	Yes	Intermediate
Lack 1993	Before–after	×	×	×	×	✓	✓	?	Yes	Weak
Lack 1994	CT	?	?	?	?	?	?	?	Yes	Weak
Lack 2005	RCT	✓	?	?	?	✓	✓	✓	Yes	Intermediate
Lack 2007	RCT	✓	?	✓	✓	✓	✓	✓	Yes	Intermediate
Lederle 2010	Crossover	?	?	×	×	?	?	×	Yes	Weak
Munch 2011	RCT	✓	?	×	×	✓	✓	?	Yes	Intermediate
Murphy 1996	RCT	✓	?	?	?	✓	?	?	Yes	Intermediate
Pallesen 2005	RCT	✓	?	✓	✓	✓	✓	✓	Yes	High
Suhner 2002	RCT	?	✓	✓	?	✓	✓	?	Yes	High
Yougstedt 2005	RCT	?	?	✓	?	?	✓	×	Partial	Weak

Note: ×, high risk of bias; ?, insufficient information; v, low risk of bias.

TABLE 2 Synthesis of LT intervention

Study	Insomnia type	Country	*n* (BL)	Mean sge	Women %	Irradiance			LT characteristics	Time of day			Duration of LT (days)
						Intensity (lux)	Duration (h)	Dose (lux-h)[a]		Morning	Daytime	Evening	
Akyar 2013	PSQI>5, not specified	Turkey	24 (24)	80	67	10,000	0.5	5000	-	24			30
Altena 2008	DSM-IV criteria, not specified	Netherland	38 (12)	60.6	72	10,000	2*0.5	10,000	-	12 sk		12 sk	6
Burkhalter 2014	Sleep–wake disturbances (sleep assessment interview)	Switzerland	30 (15)	60.7	50	10,000	0.5	5000	-	15			3
Campbell 1991	Sleep complaint (mostly sleep maintenance insomnia) of the elderly	USA	10 (6)	68.4		4000 to 5000	2	8000–10,000	-			6	9
Campbell 1993	Sleep maintenance insomnia of the elderly	USA	16 (8)	70.4	56	4000	2	8000	-			8	12
Cooke 1998	Trouble falling asleep and/or remaining asleep and/or sleep dissatisfaction	USA	10 (10)	79.4	100	2000	0.5	1000	-			10	14
Dekker 2020	insomnia disorder according to ICSD3 and DSM-5 without another neuropsychiatric diagnosis	Netherlands	86 (45)	51.0	79	10,000 lux	0.5	5000	Blue LED light, peak wavelength 470 nm, 1 W/m^2. Equivalent 10,000 lux, melanopic illuminance 770 m-lux	45			4 weeks
Friedman 2012[b]	Caregivers of memory impaired patients, no specification of sleep troubles	USA	54 (31)	63.6	83	4200	0.5	2100	-	31			14
Friedman 2009 Zeitzer 2011	ICSD-1 primary insomnia criteria	USA	51 (37)	73.35	50	4000	0.75	3000	36 W 3000° K	19		18	84
Garland 2018 Johnson 2016	Patients with cancer-related fatigue	Canada	81 (42)	66.6	?	1250	0.5	712*	White blue-enriched, peak 364–366 nm	42			28
Guilleminault 1995	Sleep initiation trouble and/or awaking in the next 2 hours	USA	30 (10)	44	56	3000	0.75	2250	-	10			28
Kirisoglu 2004	Psychophysiological insomnia with at least sleep initiation trouble	USA	30 (30)	64.8	67	10,000	0.33 or 0.75	3300–7500	-	30			60
Lack 1993	Early morning awakening	Australia	9 (9)	53.4	44	2500	4	10,000	-			9	2

TABLE 2 (Continued)

Study	Insomnia type	Country	*n* (BL)	Mean sge	Women %	Irradiance			LT characteristics	Time of day			Duration of LT (days)
						Intensity (lux)	Duration (h)	Dose (lux-h)[a]		Morning	Daytime	Evening	
Lack 1994	Early morning awakening	Australia	22 (11)	66.6	?	2500	4	10,000	75 W			11	2
Lack 2005	Early morning awakening	Australia	24 (13)	51.2	52	2500	1	10,000	75 W			13	2
Lack 2007	Sleep onset insomnia	Australia	16 (8)	29	69	2500	4	2500	100 W	8			7
Lederle 2010	PSQI>5	UK	33 (33)	66.5	70	400 or 1100	4	1600* or 4400	17,000°K and 3.6E14 photons/cm^2/s or 4000°K, 9.1E14 photons/cm^2/s	33 sk		33 sk	42
Munch 2011	Sleep complaints based on PSQI	USA	10 (10)	63.3	60	650 or 1300	2	1300* 2600	Polychromatic white 4100°K, 352microW/cm^2, 10.2E14 ph/cm^2/s or blue-enriched (°K not specified), 370 microW/cm^2, 11.1E14 ph/cm^2/s			10	5
Murphy 1996	Sleep maintenance insomnia	USA	16 (16)	73.1	50	>4000	2	>8000	-		6	7	40
Pallesen 2005	Early morning awakening	Norway	31 (17)	63.1	58	10,000	0.5	5000	4000°K			17	21
Suhner 2002	Sleep maintenance insomnia	USA	15 (15)	71.5	47	4000	2	>8000	-			15	40
Yougstedt 2005	Insomnia and/or depression	USA	90 (40)	70	68	3000	4	12,000	-	20 sk	20	20 sk	4
Total			726 (442)	64.4						289	31	227	

Note: (BL): number of patients in the bright light intervention group. *Specifies a light dose with blue-enriched light.

Abbreviation: LT, light therapy.

[a]Dose of light therapy is calculated from intensity and duration of exposure, reported to 1 h, and expressed in lux-h.

[b]Only caregivers and not demented patients were retained.

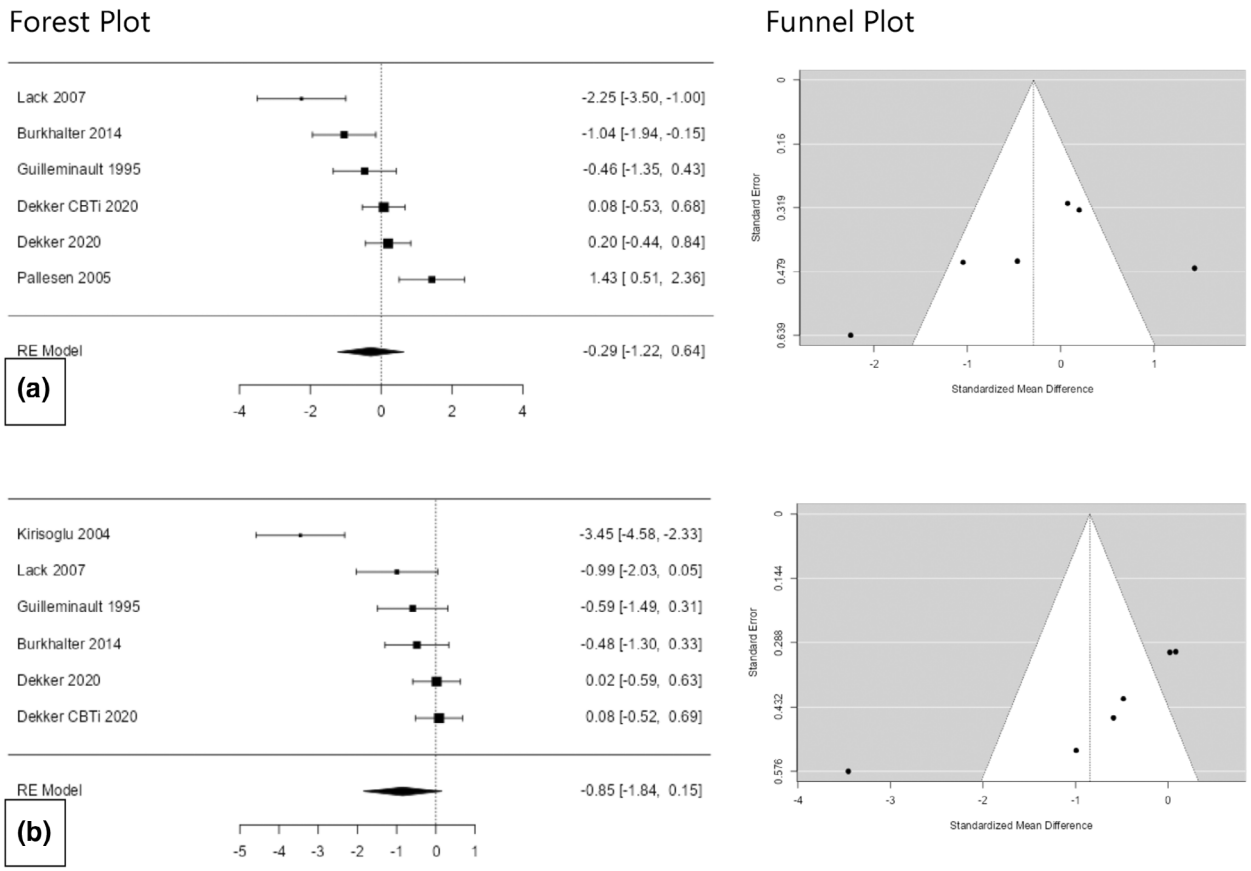

FIGURE 2 Sleep onset latency, treated vs control. (a) Objective measure; (b) subjective measure. Negative score represents a decrease of SL, interpreted as an improvement

3.2.2 | Total sleep time

There were no significant differences in the outcome of the objective measures of total sleep time between the control and LT treated groups, with a SMD of 0.26 [−0.32, 0.84] ($p = 0.38$) (I^2 79%, funnel plot asymmetry $p < 0.001$), corresponding to a weighted difference of +3.1 min (18.96 SD) (Figure 3a). No significant differences were observed when only studies examining morning exposure were considered, nor evening exposure.

The subjective measures of TST were close to significant improvement in the LT group compared with the control group, with a SMD of 0.52 [−0.03, 1.07] ($p = 0.066$), but with a publication bias (I2 69%, funnel plot asymmetry $p = 0.012$), corresponding roughly to +34.4 min (15.84 SD) (Figure 3b).

3.2.3 | Sleep efficiency

There were no significant differences in the outcome measures of sleep efficiency when comparing the light therapy treated vs the control group, with a SMD 0.25 [−0.16, 0.65] ($p = 0.236$) (I^2 55%, funnel plot asymmetry $p = 0.043$), (corresponding to a weighted difference of +1.1% (1.09 SD)) (Figure 4a) neither when analysing studies examining only morning exposure, nor in subjective measures of sleep efficiency ($p = 0.52$) (Figure 4b).

3.2.4 | Wake after sleep onset

Objective outcome measures of WASO showed a significant improvement in the LT group compared with the control group, with a SMD −0.61 [−1.11, −0.11] ($p = 0.017$) corresponding to a weighted difference of 11.2 min (SD 11.5) (I^2 65%, funnel plot asymmetry $p = 0.02$) (Figure 5a). When considering only the morning exposure studies, WASO did not show significant differences with a SMD −0.30 [−0/70, 0.10] ($p = 0.147$) corresponding to a weighted difference of −12.0 min (SD 11.47), with a low heterogeneity index (I^2 0%, funnel plot asymmetry $p = 0.57$).

Subjective outcomes measures of WASO showed a significant improvement in the LT group compared with the control group, with a SMD −1.09 [−1.43, −0.74] ($p < 0.001$) corresponding to a weighted difference of −36.4 min (SD 15.05) (I^2 0%, funnel plot asymmetry $p = 0.57$) (Figure 5b).

No significant correlation was observed between the light dose and WASO improvement in treated versus control (Figure 6a) nor in the pre–post analysis (Figure 6b).

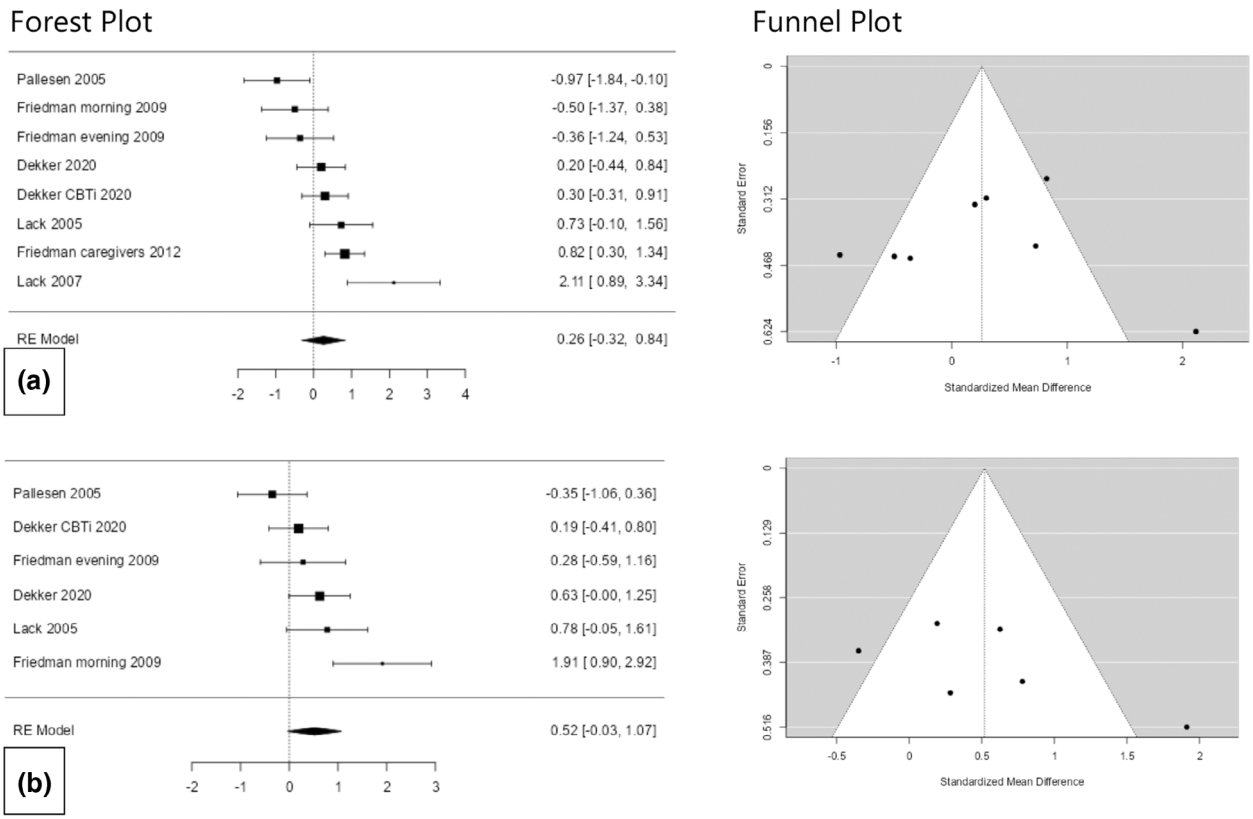

FIGURE 3 Total sleep time treated vs control. (a) Objective measure; (b) subjective measure. Positive score represents an increase of TST, interpreted as an improvement

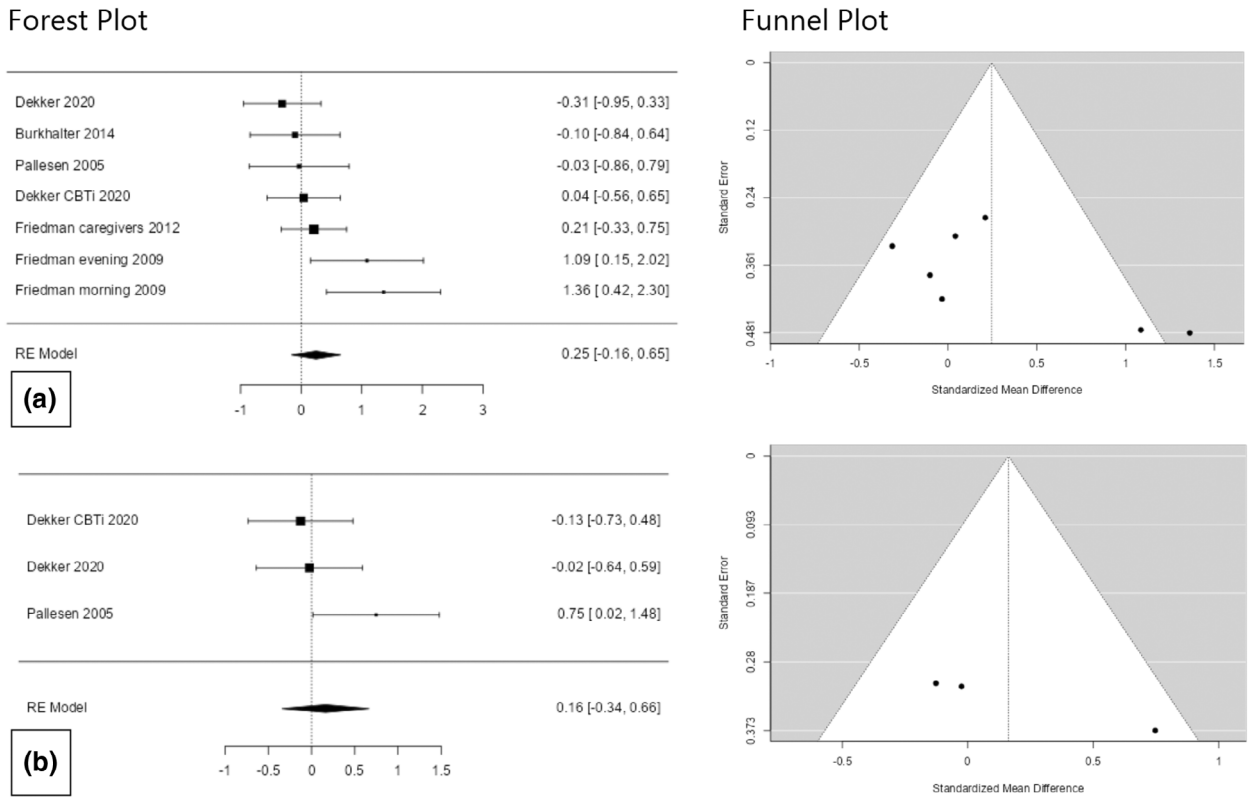

FIGURE 4 Sleep efficiency treated vs control. (a) Objective measure; (b) subjective measure. Positive score represents an increase of SE, interpreted as an improvement

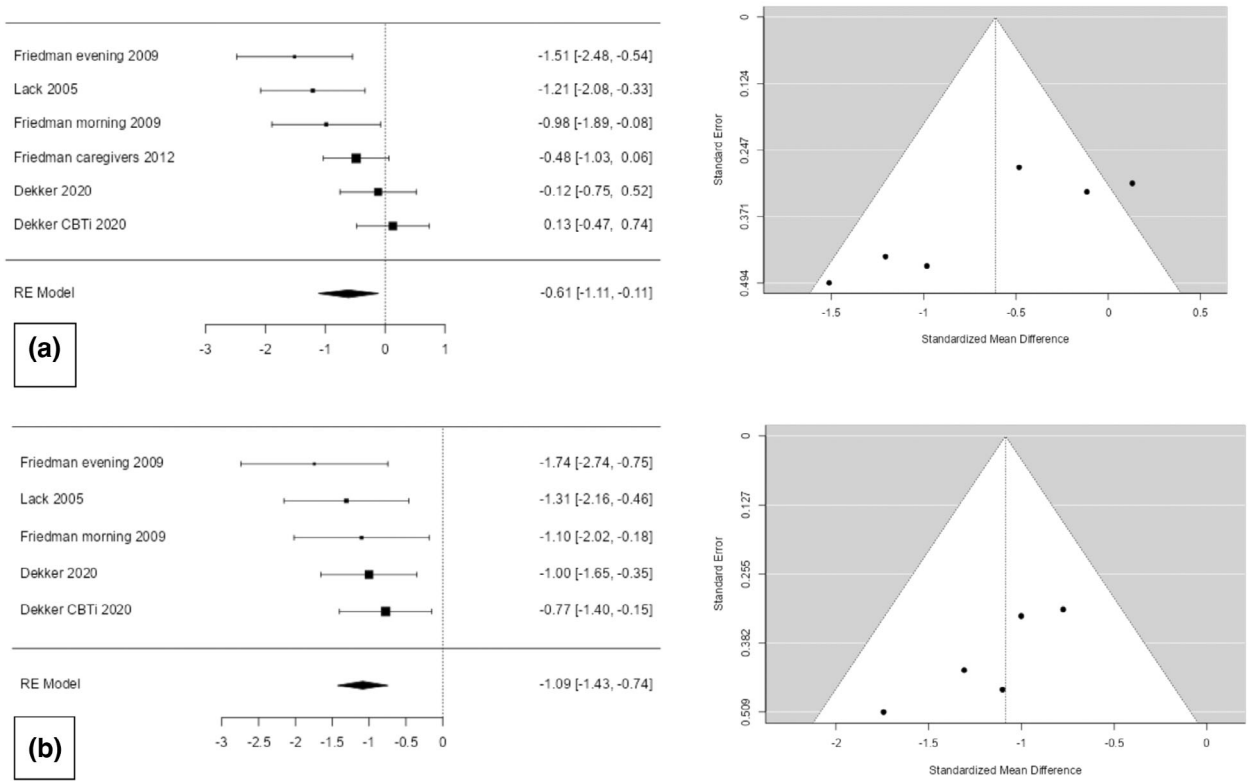

FIGURE 5 Wake after sleep onset forest plots and funnel plots treated vs control. (a) Objective measure; (b) subjective measure. Negative score represents a decreasing of WASO, interpreted as an improvement

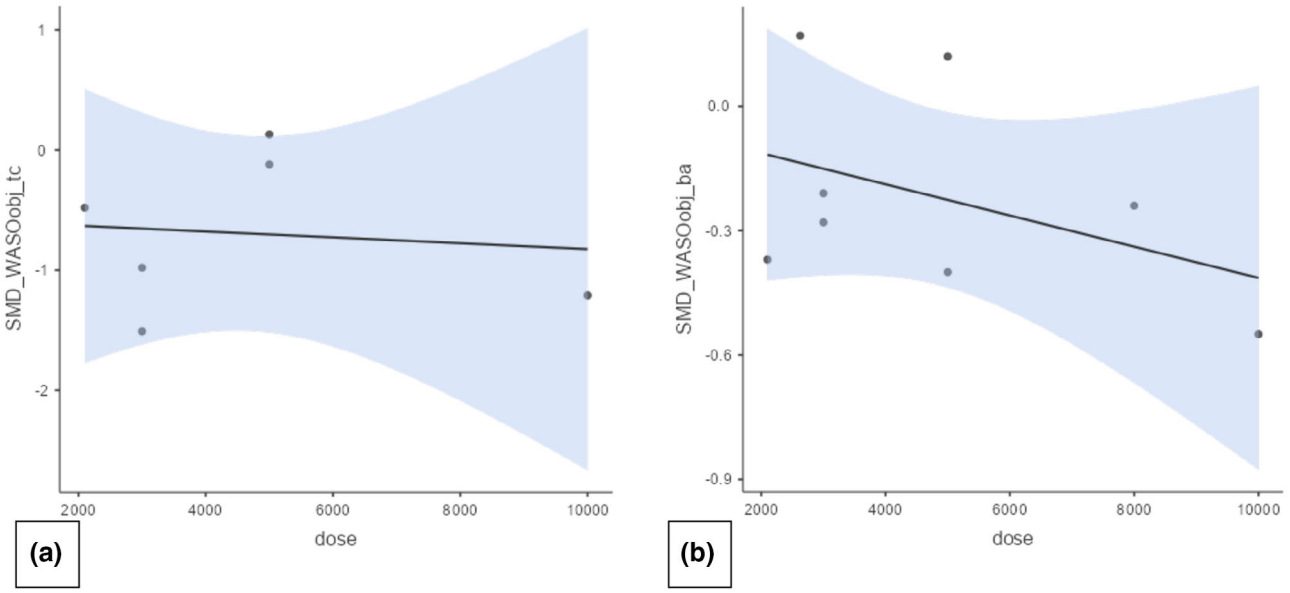

FIGURE 6 Wake after sleep onset dose–response curve (dose is expressed in lux.h). (a) Treated vs control, (b) pre-post LT [Color figure can be viewed at wileyonlinelibrary.com]

3.2.5 | Time of day of administration and phase shift of sleep–wake circadian rhythm

The number of studies was insufficient to run a separate meta-analysis based on the time of administration of light therapy. However, interventions using morning exposures (Friedman morning 2009 and Lack 2007) reported a significant phase advance, and conversely those with evening LT a significant phase delay (Friedman evening 2009 and Lack 2005).

TABLE 3 Result synthesis depending on insomnia typology

Insomnia type		Sleep initiation 6 studies 107 patients active			Sleep maintenance 11 studies 169 patients active			Early morning awakening 7 studies 110 patients active			Combined insomnia type 9 studies 152 patients active			Not defined 8 studies 240 patients active		
		n: number of studies with outcomes (x: number of participants with active bright light)														
Effect		Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	worsen
SL	Obj	3 (48)	-	-	2 (40)	2 (30)	-	-	1 (28)	-	2 (40)	4 (53)	-	-	2 (60)	1 (10)
	Subj	5 (70)	-	-	4 (69)	3 (36)	1 (17)	-	2 (56)	1 (17)	4 (62)	3 (23)	1 (17)	1 (24)	3 (102)	-
TST	Obj	3 (48)	-	1 (18)	3 (53)	1 (17)	1 (18)	3 (33)	1 (27)	1 (18)	3 (53)	1 (13)	1 (18)	-	3 (116)	-
	Subj	4 (58)	1 (12)	1 (18)	4 (63)	4 (60)	1 (18)	3 (33)	3 (40)	1 (18)	4 (63)	4 (52)	1 (18)	3 (88)	3 (104)	-
SE	Obj	-	1 (35)	-	2 (19)	2 (52)	-	-	2 (54)	-	-	2 (54)	-	2 (48)	3 (86)	-
	Subj	3 (59)	-	-	4 (67)	3 (45)	-	2 (45)	2 (32)	-	4 (67)	2 (32)	-	4 (96)	4 (104)	-
WASO	Obj	1 (10)	1 (35)	-	3 (29)	1 (37)	-	2 (24)	1 (37)	-	2 (23)	1 (33)	-	2 (41)	2 (82)	-
	Subj	2 (47)	1 (10)	-	4 (68)	2 (25)	-	4 (69)	1 (15)	-	4 (68)	2 (25)	-	2 (36)	3 (94)	-
TIB	Obj	1 (37)	-	-	1(37)	-	-	1 (37)	-	-	1 (37)	-	-	-	2 (85)	-
	Subj	-	-	-	-	-	-	-	-	-	-	-	-	-	1 (45)	-
Delay/advance	Obj	2 (45)	-	-	2 (50)	-	-	4 (70)	-	-	2 (50)	-	-	2 (48)	1 (40)	-
	Subj	2 (45)	-	-	4 (86)	1 (17)	-	6 (93)	1 (17)	-	5 (82)	1 (17)	-	3 (58)	1 (40)	-
Sleepiness/fatigue		6 (110)	1 (6)	-	-	2 (25)	-	4 (76)	2 (15)	-	6 (115)	2 (25)	-	4 (80)	1 (33)	-
ISI/sleep qual		3 (55)	1 (7)	-	-	3 (39)	-	3 (63)	2 (30)	-	3 (62)	3 (39)	-	4 (121)	3 (86)	-
Mood		2 (27)	1 (10)	-	-	2 (23)	-	2 (30)	1 (13)	-	1 (19)	2 (23)	-	2 (55)	2 (41)	-
Performance		2 (51)	-	-	-	2 (13)	-	1 (19)	1 (13)	-	1 (19)	1 (13)	-	-	2 (78)	-
Quality of life		3 (33)	-	-	-	2 (13)	-	1 (19)	1 (13)	-	1 (19)	1 (13)	-	1 (15)	2 (78)	-
Side effect		1			2			2			2			2		
Compliance		3			2			6			6			4		

TABLE 4 Synthesis of light therapy intervention characteristics

Light therapy period		Morning 9 studies 224 active light 402 total	Daytime 3 studies 31 active light 81 total	Evening 11 studies 126 active light 253 total	Morning-evening 3 studies 65 active light 161 total	« dim » red light* 11 studies 154 patients
		n: number of studies with outcomes (x: number of participants with active bright light)				
<2000 lux-h		-	-	2 (15)	1 (12)	<90 lux
2000–5000 lux-h		8 (182)	3 (31)	3 (59)	1 (21)	90–150 lux
>5000 lux-h		1 (35)	-	7 (75)	2 (32)	>150 lux
Sleep initiation		4 (67)	-	1 (18)	1 (12)	2 (22)
Sleep maintenance		4 (44)	2 (11)	7 (94)	1 (12)	5 (51)
Early morning awakening		1 (19)	1 (5)	7 (98)	-	6 (62)
Mixed		4 (55)	-	5 (81)	-	4 (47)
Not defined		6 (167)	1 (20)	2 (7)	2 (43)	3 (82)
Duration of treatment (days)	Short	2 (23)	1 (20)	3 (33)	2 (32)	5 (52)
	Intermediate	1 (31)	-	4 (41)	-	4 (49)
	Long	5 (116)	2 (11)	3 (40)	1 (33)	2 (53)
Objective measures		9 (224)	3 (31)	11 (126)	2 (53)	11 (154)
Subjective measures		9 (224)	3 (31)	11 (126)	3 (65)	11 (154)

Note: Duration of treatment: short >7 days, intermediate between 7 and 30 days, long >30 days. Objective measures: data from polysomnography or actimetry. Subjective measures: data from sleep agenda and questionnaires.

3.3 | Qualitative analysis

All studies were included in a qualitative analysis of the results. We performed a first analysis according to the insomnia typology: sleep initiation, sleep maintenance, early morning awakening, or combined type of insomnia (Appendix 3). A majority of studies (17/22) had no clear insomnia criteria, and no fully detailed descriptions of the insomnia characteristics of the participants were provided. We secondly performed an analysis according to the time of day of the exposure to light therapy: morning, daytime, evening, or combined morning–evening exposure.

3.4 | Results according to insomnia typology

A majority of studies (17/22) had no clear insomnia criteria, and no complete description of the participants' insomnia characteristics (Table 3). Some specified at least one criterion, mainly nocturnal symptoms: sleep initiation problems (8), sleep maintenance troubles (13), early morning awakening (8). Twelve studies specified that patients could have combined sleep disturbances, and eight gave no information about insomnia characteristics. When the information about insomnia typology was mentioned, we artificially split the number of concerned patients in the different typology groups, but no studies presented the outcomes following those sub-groups. In this context, from this qualitative analysis, no clear conclusions could be drawn. The detailed results for each outcome are presented in Table 3.

The seven studies involving patients with early morning awakenings (110 participants in the active group) mainly applied light therapy in the evening, whereas studies including subjects with other insomnia typology mainly applied LT in the morning or in both morning and evening. Data were insufficient to conclude the best period of treatment by insomnia typology. A majority of results were non-significant, and the outcomes that showed an improvement concerned more frequently subjective than objective assessments. A shortening of TST was only observed for patients with evening exposure.

3.5 | Results according to timing of light therapy administration

The results here focus on pre–post intervention studies as the results of comparisons between LT and control groups were too sparse. The results were interpreted as non-significant if the improvement was related to both the active and placebo groups. The details of interventions are presented in Table 4. Detailed results for each outcome are presented in Table 5.

Compliance with light therapy was rarely reported, especially for long-duration protocols: nine studies did not mention it; six applied LT and monitored the compliance during hospitalisation or in institutions only, two were based on a daily call as a reminder, and five reported it with clear information: compliance was good, and usually better in the active group. Regarding side effects, they were even less often reported, only three studies providing informative data on side effects. Pallesen et al. (2005) reported significantly more side effects (mostly mild) in the dim red light (DRL) group, especially headache, eye strain, and fatigue.

TABLE 5 Results synthesis according to light exposure period

Light therapy period		Morning 9 studies 224 active light 402 total			Daytime 3 studies 31 active light 81 total			Evening 11 studies 126 active light 253 total			Morning-evening 3 studies 65 active light 161 total			« dim » red light* 11 studies 154 patients		
		n: number of studies with outcomes (x: number of participants with active bright light)														
Effect		Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	Worsen	Improve	NS	worsen
SL	Obj	3 (48)	2 (60)	-	-	-	-	-	2 (30)	1 (10)	-	-	-	1 (14)	4 (47)	-
	Subj	5 (81)	2 (60)	-	-	1 (5)	-	1 (10)	5 (56)	1 (17)	1 (12)	-	-	1 (39)	1 (14)	-
TST	Obj	3 (48)	2 (64)	-	-	1 (20)	-	3 (33)	1 (17)	1 (18)	-	1 (20)	-	3 (42)	5 (67)	-
	Subj	5 (96)	2 (50)	-	1 (20)	1 (5)	-	4 (43)	4 (59)	1 (18)	1 (20)	1 (12)	-	2 (21)	2 (18)	-
SE	Obj	2 (46)	2 (64)	-	1 (6)	1 (20)	-	2 (13)	2 (35)	-	1 (33)	1 (20)	-	1 (23)	4 (56)	-
	Subj	3 (88)	3 (88)	-	1 (6)	1(5)	-	3 (36)	4 (58)	-	2 (45)	-	-	2 (53)	1(14)	-
WASO	Obj	1 (10)	4 (137)	-	-	1 (20)	-	2 (19)	2 (29)	-	1 (33)	1 (20)	-	3 (62)	4 (53)	-
	Subj	3 (74)	2 (73)	-	-	1 (5)	-	4 (26)	4 (6583)	-	1 (12)	0	-	-	2 (25)	-
TIB	Obj	1 (19)	2 (37)	-	-	1 (20)	-	1 (18)	-	-	-	1 (20)	-	-	2 (37)	1 (8)
	Subj	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Delay/advance	Obj	3 (60)	2 (68)	-	-	1 (20)	-	4 (51)	-	-	1 (33)	1 (20)	-	2 (16)	5 (42)	-
	Subj	4 (69)	-	-	-	3 (31)	-	8 (91)	-	-	1 (33)	1 (20)	-	-	1 (4)	-
Sleepiness/fatigue		6 (118)	3 (47)	-	1 (6)	-	-	6 (77)	2 (25)	-	-	1 (33)	-	2 (30)	5 (51)	-
ISI/sleep qual		6 (99)	3 (48)	-	2 (26)		-	3 (44)	2 (30)	-	1 (20)	1 (33)	-	4 (77)	2 (21)	-
Mood		4 (73)	2 (37)	-	1 (20)	-	-	1 (11)	3 (41)	-	1 (20)	1 (33)	-	1 (23)	3 (30)	-
Performance		2 (27)	-	-	1 (5)	-	-	1 (7)	2 (31)	-	-	1 (33)	-	-	1 (8)	-
Quality of life		3 (42)	-	-	-	-	-	-	2 (31)	-	-	1 (33)	-	-	2 (22)	-
Side effect		2 (60)			-			1 (17)			-			-		
Compliance		5 (94)			2 (11)			7 (59)			-			-		

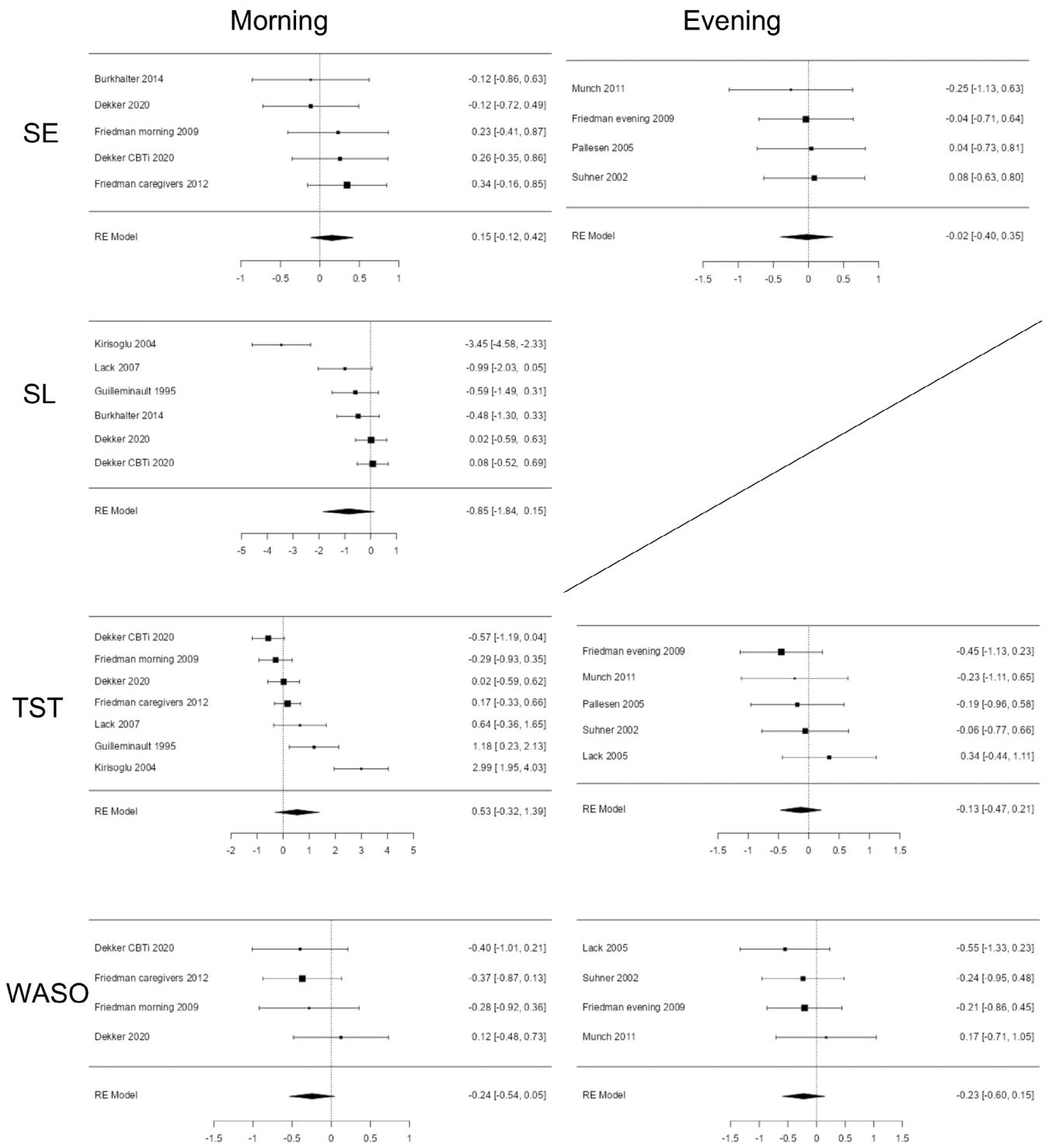

FIGURE 7 Meta-analyses of the effect pre-post LT on objective sleep outcome, by the timing of the exposure. SL, sleep onset latency; SE, sleep efficiency; TST, total sleep time; WASO, wake after sleep onset

3.5.1 | Morning exposure

The nine studies using morning exposure included 224 participants with active bright light. A majority received intermediate doses (between 2000 and 5000 lux-h), and a treatment duration of 40 days or more (five studies, 116 active patients). For all outcomes, the meta-analysis showed high heterogeneity and because we were missing data for the controls a meta-analysis of pre–post LT was conducted. Regarding objective sleep measures, SE, SL, TST, and WASO showed non-significant results (Figure 7). Qualitative analysis showed no worsening of objective or subjective sleep quality. Studies are distributed between an improvement (mostly on subjective criteria), and

TABLE 6 Effects of dim red light on sleep

Study	*n*	Period	Red light specifications		SL		TST		SE		WASO		Circadian phase-shift	Sleepiness - fatigue	ISI - sleep quality	Mood	Performance	Quality of life
			Intensity (lux)	Dose (lux-h)	Objective	Subjective	Objective	Subjective	Objective	Subjective	Objective	Subjective						
Friedman 2009 morning	7	Morning	50	37.5	-	-	NS	NS	NS	-	NS	NS	NS	NS	NS	-	-	NS
Friedman 2012	23	Morning	90	45	-	-	NS	-	↗	-	↘	-	-	NS	↗	↗	-	-
Lack 2007	8	Morning	100	100	NS	-	NS	-	-	-	-	-	NS	NS	↗	NS	NS	NS
Garland 2018 Johnson 2016	39	Morning	<400	<200	-	-	-	-	-	-	-	-	-	-	↗	-	-	-
Yougstedt 2005	20	Skeleton	50	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Friedman 2009 evening	7	Evening	50	37.5	-	-	NS	↗	NS	-	NS	NS	NS	↘	↗	-	-	NS
Campbell 1991	8	Evening	50	100	-	-	-	-	-	-	NS	-	-	-	-	-	-	-
Campbell 1993	6	Evening	50	100	NS	-	NS	-	NS	-	NS	-	NS	-	-	-	-	-
Pallesen 2005	10	Evening	200	100	↘	NS	NS	↗	NS	↗	-	-	-	NS	NS	-	-	-
Lack 2005	11	Evening	100	400	-	-	NS	NS	-	-	NS	NS	ß	NS	←	NS	-	-
Lack 1993	2	Evening	150	600	-	-	-	-	-	-	-	-	NS	-	-	-	-	-
Lack 1994	11	Evening	200	800	-	-	-	-	-	-	-	-	-	NS	-	NS	-	-

non-significant results. A phase advance was observed in all studies: in the three studies that recorded those data objectively (Burkhalter et al., 2015; Friedman et al., 2009; Lack & Wright, 2007), and in the three that recorded the data subjectively (Burkhalter et al., 2015; Friedman et al., 2009; Lack & Wright, 2007).

3.5.2 | Evening exposure

The 11 studies using evening exposure included 126 participants with active bright light. A majority received high dose (over 5000 lux-h), and the treatment duration was equally distributed to short (<7 days), intermediate, and long (>1 month). According to the meta-analysis, no significant results were observed for SE, TST, nor WASO, and a lack of data did not allow the calculation of SL. Qualitative analysis showed no worsening of objective or subjective sleep quality, except one with a worsening of objective and subjective TST. The studies are distributed between an improvement (mostly on subjective criteria) and non-significant results. An objective phase delay was observed in four studies and eight studies reported a subjective phase delay.

3.5.3 | Daytime exposure

The three studies using daytime exposure included 31 participants with active light therapy administered at a high dose (over 5000 lux-h). A majority of the outcomes are non-significant. No worsening of objective or subjective sleep quality was observed. No subjective phase shift was observed.

3.5.4 | Combined morning-evening exposure

The three studies combining morning and evening exposures included 65 participants with active bright light. They received equally low, intermediate, or high doses. Some improvement was observed especially for SE and WASO. Subjective quality of sleep was mostly non-significant. No worsening of objective or subjective sleep quality was observed. One study observed a phase delay when participants were exposed to blue-enriched light (1100 lux i.e. 4400 lux-h), and phase advance when they were exposed to low-intensity light (400 lux i.e. 1600 lux-h) (Lederle et al., 2010); another one found no phase shift.

3.5.5 | Dim red light

A total of 12 studies used dim red light as a placebo treatment, and 11 specified the intensity: four were around 50 lux, four between 90 and 150 lux, and three between 200 and 400 lux. Standardised doses of red light ranged between 37.5 lux-h and 800 lux-h. Many studies did not specify the results in the DRL group, thus over half of the data are missing. Most studies reported a non-significant effect of DRL, although some showed a significant effect indicating an improvement in objective SL, SE, and WASO as well as subjective TST, SE, sleep quality, and mood. The results are shown in Table 6.

4 | DISCUSSION

4.1 | Main results

In summary, most of the present meta-analyses showed high heterogeneity and publication bias, limiting the interpretation of the results. In comparison with control conditions light therapy in the treatment of insomnia significantly improved WASO, but not other sleep measures. No dose–response effect was observed. Not enough studies have been conducted to determine the difference of effect between morning and evening exposure but those preliminary results point toward a greater improvement of SL and TST with morning exposure. A phase-shift was observed in some studies, a phase-advance for morning exposure and a phase-delay for evening exposure, as expected. The effects of dim red light are non-conclusive, but do raise the hypothesis of an improvement in sleep quality and some other sleep parameters.

4.2 | Limitations

Most studies were conducted on a small number of participants, thus with limited statistical power. The precise typology of insomnia was rarely specified. We also chose to include some older studies in which insomnia diagnostic criteria were not clearly specified, but the sleep troubles mentioned in those studies referred at least to one insomnia complaint.

The interventions were heterogeneous, in terms of time of day, intensity, and duration of exposure to light therapy, but also in terms of control group, measurement method, and questionnaires. Therapeutic compliance and adverse events were rarely reported. The overall quality of the studies selected was low to intermediate, with only five studies having a low risk of bias. Interpretation of the results was further limited by both a high heterogeneity and a high risk of publication bias observed in most meta-analyses. Six of the 22 studies based the objective outcomes on polysomnography done at the hospital, with short study duration (2 to 12 days) (Campbell & Dawson, 1991; Lack et al., 2005; Lack & Wright, 1993; Münch et al., 2011; Murphy & Campbell, 1996; Youngstedt et al., 2005). Those conditions differ from the real living conditions of insomniacs. Studying a larger population of insomniacs in their homes would provide a more appropriate answer.

4.3 | Positive results and trends

Despite these limitations, this systematic review identified additional interesting results and trends. No worsening in insomnia or sleep

quality has been observed, except in one study with evening light therapy. In terms of objective results, we were able to highlight a trend towards improving sleep efficiency and the duration of nocturnal awakenings, regardless of the time of exposure. An improvement in sleep latency was shown with morning light therapy. These results remain to be confirmed due to the great heterogeneity of the studies that could be used in the meta-analysis. Despite the subjective outcomes being too heterogeneous to carry out a statistical analysis, all studies but three showed an improvement, particularly with regard to the quality of sleep and the feeling of drowsiness or fatigue. Finally, although not a main goal, the observed phase shifts were consistent with the time of day of light exposure, which indirectly indicated a good compliance.

4.4 | Choice of the control

The choice of control remains to be discussed: dim red light is often used as a control, but does not seem to be a perfect placebo, especially above a certain intensity (≥200 lux) in the evening. Pallesen in 2005 found a significant decrease of sleep latency in this group, from 15.2 to 8.7 min, with a non-significant increase of total sleep time from 6 h 28 to 6 h 40. As shown in Table 6, a majority of the results in dim red light were non-significant, as can be expected in a placebo group, but when positive, the trend was always in the same direction of an improvement of sleep parameter and subjective sleep quality. This is in line with one study from our group suggesting that high intensity red light might facilitate sleep (van der Meijden et al., 2018). Still, it could be used as a correct "placebo" at a lower intensity, and in morning or daytime exposure: first, it enables a comparison of results with many studies, as it is the most frequently used. Second, there is a good acceptability of the participants for this intervention. It is also important to be aware that dim red light might have a positive effect and thus reduce differences between groups. This should be taken into account especially if we expect only a small effect size. Other types of placebo conditions need to be developed, such as an inactivated ioniser used by Dekker (Dekker et al., 2020). Last, one should consider that light therapy is a visual and time consuming therapy. Applying light therapy by itself modifies the patient's behaviour, imposing a daily time frame. This behavioural effect is likely to be all the more important as the duration of exposure is long, especially with static devices, compared with portable devices. Then, it would be necessary to choose a control condition with the same behavioural requirement.

4.5 | Practical issues

From these results, the operational use of light therapy for insomniacs cannot be established directly. However, the present observations do allow us to draw a framework for its use and to provide insights for future research (Table 7).

4.6 | Parameters to be considered

4.6.1 | Circadian and non-circadian effect

As Maanen et al. showed in their meta-analysis, a circadian phase-shift of the sleep–wake rhythm greatly contributed to the effect of light therapy for insomniac patients (Maanen et al., 2016). Taking into account that the chronobiological aspect of insomnia is a prerequisite for choosing the time of administration of LT exposure (Lack & Wright, 2007). This is also relevant as it is included in sleep hygiene advice (Stepanski & Wyatt, 2003). Moreover, other factors could influence the efficacy of morning vs evening light therapy. Zeitzer analysed the difference of sensitivity between morning and evening light therapy and hypothesised that a greater light exposure during the daytime could decrease the effect of evening light therapy (Zeitzer et al., 2011). Therefore, intra-individual differences including, for example, circadian preference or a daytime light exposure photic dose should be considered before defining the characteristics of light therapy, and towards a personalised medicine approach to treatment.

Last, sensitivity to photic exposure can also be influenced by season, as it was proven for patients suffering from seasonal affective disorders. In Nordic countries, insomnia has been studied throughout the seasons, and a seasonal impact was observed in some studies, depending on the season and daylight duration, especially with the observation of lower sleep duration during spring (Friborg et al., 2012; Karunanayake et al., 2021).

If the circadian aspect of insomnia has to be taken into account, this review tended to emphasise a non-circadian direct effect of light therapy on sleep quality. There was a trend towards improved sleep efficiency and WASO, regardless of the time of administration of exposure to light therapy. Subjective data also indicate it could have an impact on daytime alertness and performance. These findings need to be confirmed but are consistent with the recent literature that emphasises the significance of the direct effects of light on sleep, alertness, and behaviour (Bourgin & Hubbard, 2016; Hubbard et al., 2013). This aspect would orient towards the clinical use of morning or daytime light therapy, whereas evening light therapy would be favoured for insomnia with phase advance, more commonly observed in the elderly.

4.6.2 | Insomnia typology

Light therapy could be effective for several insomnia typologies, but with respect to the time of day of exposure and the individual circadian preference of the patients: sleep onset insomnia should be more sensitive to morning light therapy, with an intended circadian effect. Sleep maintenance insomnia might be improved by light therapy independent of circadian effects. This might enable more flexibility in duration and the time of exposure, depending on the patients' preferences. The results are non-conclusive for early morning awakening insomnia: the circadian aspect seems insufficient, but one should be

TABLE 7 Light parameters to be considered according to insomnia typology. [Color table can be viewed at wileyonlinelibrary.com]

Insomnia typology	Sleep initiation	Sleep maintenance	Early morning awakenings	Combined	Daytime consequences
Circadian effect targeted	Intended phase advance	No	Intended phase delay if sufficient TST	No or depending on the combination	No
Period of exposure	Morning	Morning/daytime Not in the end of afternoon	Daytime/evening	Morning/daytime	Morning/daytime
Duration of exposure	20 min to 4 h[a]	20 min to 4 h[a]	Daytime: 20 min to 4 h Evening: Shorter (<1 h)	20 min to 4 h[a]	20 min to 4 h
Light intensity	≥2000 lux-h[b] ? melanopic lux	≥2000 lux-h[b] ? melanopic lux	Daytime: ≥2000 lux-h[b] ? melanopic lux Evening:?	≥2000 lux-h[b] ? melanopic lux With EMA:?	≥2000 lux-h[b] ? melanopic lux
Light spectrum	White or blue-enriched	White or blue-enriched	Daytime: White or blue-enriched Evening: no blue-enriched White or red?	?	White or blue-enriched

Note: green: solid scientific basis. orange: hypothesis with some scientific basis, need to be confirmed. red: hypothesis, need some proof of concept.
[a]≥20 min up to 4 h, based on existing literature. Duration also depends on the intensity.
[b]Equivalent of full white spectrum, based on previous studies. Future studies should specify melanopic lux, light temperature and spectrum.

aware that evening light therapy could suppress melatonin, and shorten sleep duration.

4.6.3 | Light characteristics

The characteristic of light is the key point to evaluate, in order to be able to answer whether or not light therapy is efficient on insomnia and how. The properties of light administration have to be taken into account as follows: intensity, spectrum, history of light exposure, time of the day, and duration of light exposure.

Van Maanen has shown that a higher intensity was more effective. We could not confirm a dose effect of light therapy, tested only on WASO (the only significant result). This might be explained for several reasons: the range of light intensity was narrow with many studies between 2000 and 5000 lux.h. We choose by team consensus to report the amount of light therapy received as a dose calculated in lux referred to 1 h in order to compare studies with different LT protocols, which can be discussed. Light intensity cannot be reduced to a lux dose. Indeed, lux is a usual way to reflect intensity of a white full-spectrum light, but not for a specific spectrum, as red or blue-enriched light. As often specified in the most recent studies, future studies should specify the wavelength, the intensity in photon/s/cm^2 and/or in Watt/cm^2, the colour temperature in Kelvin. Several studies showed that a lower intensity of blue-enriched light had the same efficacy as full spectrum light (Glickman et al., 2006; Meesters et al., 2011; Vandewalle et al., 2007). Lucas emphasises the importance of more precise measures of light (Lucas et al., 2014). He proposes methods to quantify effective irradiance independently for each photoreceptive input, such as melanopic illuminance (expressed in melanopic-lux), in order to facilitate the comparison of polychromatic light. As a result, more recent studies have detailed light characteristics.

The tolerance and side effects of light therapy have to be considered in order to define the characteristics of light exposure. Side effects were rarely mentioned in the studies, but are now well established for other diseases such as SAD. Most of them are transient and reversible. Looking at ocular risk Kobayashi controlled the ocular effect after white full-spectrum LT, and found no worsening after treatment (Kobayashi et al., 2001). This has also been evaluated for blue-enriched light, as it is known to be close to a wavelength with more retinal toxicity, and the results are reassuring (Brouwer et al., 2017). Moreover, blue-enriched devices have less illuminance than white LT, and lower to equal quantity of photons/s/cm^2 in this wavelength. However, Meesters observed that participants generally appreciated less blue-enriched light (colour temperature of 17,000°K) than the broad-wavelength white light (5000° K) (Meesters et al., 2011).

4.6.4 | Time of day and duration of exposure

Both time of day and the duration of bright light exposure have implications in terms of the photic dose and the effect on circadian rhythms. A longer exposure allows higher cumulative doses, but could lead to less compliance, especially in younger, active patients. The choice of intensity and duration should then also depend on practical aspects.

In addition, the response to light is variable depending on the surrounding conditions. Zeitzer experienced it in their non-conclusive study about morning or evening bright light (Friedman et al., 2009; Zeitzer et al., 2011). They concluded that daytime light exposure intensity may influence the response to evening bright light, but not to morning bright light. This seems to be confirmed by recent studies on the influence of self-luminous ebooks on sleep (Rångtell et al., 2016).

We saw that evening exposure raises two risks: first, a lack of efficacy if the daytime light exposure was too high, second, a shortening of the total sleep time. Then, evening LT should not be recommended for insomnia, except for specific indications, such as physiological phase advance in the elderly.

The choice of morning light therapy seems especially appropriate in case of sleep initiation insomnia. Daytime light therapy has not been studied sufficiently to evaluate its efficiency. This option could yet theoretically be interesting for two reasons: the first is the global underexposure to light, both in active adults (Leger et al., 2011), and even more in the elderly and nursing home residents (Shochat et al., 2000). The second is an expected improvement of some diurnal symptoms of insomnia, alertness, and mood. The effect on nocturnal symptoms of insomnia, especially on awakenings remains to be assessed, but the results of the present literature review is encouraging.

In conclusion, chronic insomnia is a complex disorder involving many mechanisms, and treatment cannot be reduced to one single therapy. Light therapy appears to be efficacious compared with a placebo for objective and subjective WASO. Its efficacy still needs to be proven for other sleep parameters and insomnia typologies. It would probably be more effective in a multi-component intervention, for instance personalised therapeutic approaches also including sleep hygiene, behavioural components of CBT-I, or melatonin. Indeed, current consensus favours multi-component interventions to confer the most benefit in treating chronic insomnia (McLaren et al., 2023).

DATA AVAILABILITY STATEMENT

data available on request

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