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OBJECTIVE AND SUBJECTIVE CHARACTERISTICS OF SLEEP IN CHRONIC INSOMNIA

Mgr. Karolina Janků

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Speciality: Neurosciences

Chair of Speciality Council: Prof. MUDr. Jan Laczó, Ph.D.

Training Centre: National Institute of Mental Health, Topolová 748, Klecany, 250 67

Author: Mgr. Karolina Janků

Supervisor: PhDr. Jana Kopřivová, Ph.D.

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SUMMARY

Background: Insomnia is one of the most prevalent sleep disorders, negatively impacting the quality of life and increasing the risk of other health problems. Many patients with insomnia underestimate their sleep quantity compared to objective sleep measures. This objective and subjective sleep discrepancy (sleep misperception) occurs in different insomnia subtypes as well as in insomnia with a comorbid psychiatric disorder. Although previous research suggests that the sleep discrepancy reflects specific objective sleep alterations, the results of studies are inconsistent. Moreover, its relation to psychiatric comorbidities is not clear, as well as its role in the insomnia treatment.

Aims: The theoretical part of the present thesis aimed to provide an overview of the recent research on sleep discrepancy in insomnia. The experimental part consists of four studies with the following goals: (1) to explore sleep electroencephalographic (EEG) correlates of sleep discrepancy in insomnia patients (Study 1); (2) to assess the association between sleep discrepancy and psychopathology (Study 2); (3) to examine changes of sleep discrepancy during and after the cognitive behavioural therapy for insomnia (CBT-I; Study 3); (4) to assess whether the additional chronotherapeutic tool can enhance the effect of CBT-I on sleep parameters.

Methods: All four studies included patients with chronic insomnia. Study 1 also included a good sleeper control group (GS). In this study, patients were further divided into three insomnia subtypes according to the objective sleep parameters, and the presence or absence of sleep discrepancy. Subjective and objective (polysomnographic; PSG) sleep parameters were compared between the groups. The sleep EEG activity was further analysed by a power spectral analysis. Study 2 compared the degree of sleep discrepancy between groups of insomnia patients with and without depressive symptoms. In both of these PSG studies, correlational analyses were conducted to examine EEG correlates of sleep discrepancy. Objective sleep measures in Studies 3 and 4 were obtained by actigraphy. Study 3 compared the treatment outcome in patients with different subjective sleep evaluations. Study 4 explored the effect of CBT-I in combination with a blue-light blocking glasses compared to the CBT-I group with clear placebo glasses.

Results: Both PSG studies found a significant association between a reduction of REM sleep proportion and a degree of sleep discrepancy. Reduced REM sleep was also the only common feature found in the two different groups of patients with sleep misperception. A higher degree of sleep discrepancy was observed in insomnia patients with depressive symptoms, and this tendency was associated with depression severity. Studies on CBT-I revealed a significant reduction of sleep discrepancy after the therapy. In Study 3, patients with accurate estimates of sleep at baseline tended to overestimate sleep quantity after the CBT-I. A similar result was found in Study 4. Only patients in the CBT-I group with blue-light blocking glasses tended to overestimate their sleep quantity after the treatment when compared to the CBT-I group with placebo glasses.

Conclusions: The findings are in line with the assumption that insomnia patients with sleep discrepancy show specific sleep alterations, highlight the importance of REM sleep in subjective evaluation of sleep, point out the association between sleep discrepancy and depressive symptoms, and prove the efficacy of CBT-I in reducing sleep discrepancies. The additional chronotherapeutic tool showed promising results by enhancing the effect of CBT-I. Future studies should explore the role of sleep discrepancy in common pathophysiology of insomnia and depression, use more sensitive neurophysiological measures, and also involve patients who overestimate their sleep quantity.

SOUHRN

Úvod: Insomnie je jednou z nejčastějších poruch spánku, která negativně ovlivňuje kvalitu života a zvyšuje riziko rozvoje dalších zdravotních potíží. Jedním z častých fenoménů, objevujících se u pacientů s insomnií, je podhodnocování délky spánku ve srovnání s objektivním měřením. Tato objektivní a subjektivní spánková diskrepance (spánková mispercepce) se může vyskytnout u různých podtypů insomnie, a u insomnie komorbidní s psychiatrickým onemocněním. Ačkoliv studie poukazují na to, že spánková diskrepance reflektuje specifické objektivní změny spánku, jejich výsledky nejsou konzistentní. Stejně tak není jasné, jakou roli hraje tento fenomén ve vztahu insomnie a komorbidní psychopatologie, a jak se mění během léčby.
Cíle: Cílem teoretické části této dizertace bylo poskytnout literární přehled současných studií zaměřených na spánkovou diskrepanci u insomnie. Praktická část je tvořena čtyřmi studiemi, které měly za cíl: (1) nalézt spánkové elektroencefalografické (EEG) koreláty spánkové diskrepance (Studie 1); (2) zjistit, zda existuje vztah mezi spánkovou diskrepancí a psychopatologií (Studie 2); (3) zkoumat změny ve spánkové diskrepanci během a po kognitivně behaviorální terapii insomnie (KBT-I; Studie 3); (4) posoudit, zda chronoterapeutická intervence může zvýšit efekt KBT-I na spánkové parametry (Studie 4).
Metody: Všechny čtyři studie zahrnovaly pacienty s chronickou insomnií. Studie 1 zahrnovala také kontrolní skupinu zdravých dobrovolníků (KS). V této studii byli pacienti s insomnií dále rozděleni do skupin dle přítomnosti či absence spánkové diskrepance, a dle objektivních spánkových parametrů. Následně byly srovnávány rozdíly v subjektivních a objektivních (polysomnografických; PSG) parametrech spánku mezi skupinami. Spánková EEG aktivita byla dále zpracována pomocí spektrální analýzy. Studie 2 porovnávala rozdíl v míře spánkové mispercepce u pacientů s insomnií a depresivními příznaky se skupinou pacientů bez depresivních příznaků. Obě PSG studie zahrnovaly také korelační analýzy pro zkoumání EEG korelátů spánkové diskrepance. Ve Studiích 3 a 4 byl spánek objektivně měřen pomocí aktigrafie. Studie 3 navíc porovnávala efekt KBT-I u pacientů s rozdílným subjektivním

hodnocením spánku. Studie 4 srovnávala efekt kombinace KBT-I s večerním užíváním brýlí filtrujících modré světlo, s kombinací KBT-I a placebo brýlemi.
Výsledky: Obě PSG studie prokázaly signifikantní korelaci mezi sníženým množstvím REM spánku a zvýšenou mírou spánkové diskrepance. Snížené množství REM spánku bylo také jediným společným znakem nalezeným u odlišných skupin pacientů se spánkovou mispercepcí. U pacientů s depresivními symptomy byla nalezena signifikantně vyšší míra spánkové diskrepance, která pozitivně korelovala se závažností deprese. KBT-I bylo spojeno se snížením míry spánkové mispercepce. Pacienti, kteří na začátku terapie hodnotili svůj spánek v souladu s objektivním měřením, měli po KBT-I tendenci dobu spánku nadhodnocovat. Stejný výsledek byl nalezen u skupiny absolvující KBT-I v kombinaci s filtračními brýlemi, a nikoliv u KBT-I skupiny s placebo brýlemi.
Závěr: Výsledky dizertace jsou v souladu s předpokladem, že spánková diskrepance reflektuje specifické objektivní změny spánku, vyzdvihují roli REM stádia v subjektivním hodnocení délky spánku, poukazují na vztah mezi spánkovou diskrepancí a depresivními symptomy, a potvrzují efekt KBT-I na snížení míry spánkové diskrepance. Přidaná chronoterapeutická intervence ukázala slibné výsledky posílením efektu KBT-I na kvalitu spánku. Budoucí studie by měly dále prozkoumat roli spánkové diskrepance ve společné patofyziologii insomnie a deprese, použít citlivější neurofyziologické metody, a zahrnout mnohdy opomíjenou skupinu pacientů, kteří kvantitu svého spánku nadhodnocují.

1. INTRODUCTION

Insomnia is among the most prevalent sleep disorders. Its symptoms occur in approximately 30 % of the adult population, and their prevalence is still increasing (Calem et al., 2012). Insomnia symptoms include difficulties in initiating and maintaining sleep or waking up earlier than desired, as well as attention or memory impairment, mood disturbances, or behavioural problems (AASM, 2014). Interestingly, many insomnia patients do not show any objective impairment of their sleep continuity compared to subjective complaints. Prevalence of this subjective and objective sleep discrepancy (sleep misperception), ranges between 9.2 and 50 %, depending on the criteria used (Dorsey & Bootzin, 1997; Edinger & Krystal, 2003). Sleep discrepancy may occur in different insomnia subtypes. Paradoxical insomnia (PARA) patients show a substantial discrepancy between their subjective complaints and objective findings on polysomnography (PSG), which usually indicates a standard sleep quality. Sleep misperception also occurs in insomnia patients with objectively impaired sleep continuity, i.e., in psychophysiological

insomnia (PSY; psychophysiological insomnia with sleep misperception [PSY/MIS]) and in insomnia comorbid with psychiatric disorders, such as depression (Rotenberg, Indursky, Kayumov, Sirota, & Melamed, 2000). It is clinically essential to explore this phenomenon as patients with sleep misperception may develop more extensive objective impairment of sleep (Harvey & Tang, 2012). Moreover, increasing evidence suggests that sleep misperception reflects specific alterations of sleep, which are not captured by traditional sleep measures (Rezaie, 2018). These changes are usually associated with the hyperarousal, presented by a higher cortical activity during sleep (Riemann et al., 2010). However, inconsistent results exist in this field of research, probably due to a different method of differentiation of insomnia subgroups.

Although the first treatment choice, cognitive behavioural therapy (CBT-I), seems to be effective in correcting sleep discrepancies (Cronlein et al., 2019), studies describing the mechanism of its impact on sleep are lacking, with a majority of them assessing only subjective sleep parameters (van Straten et al., 2018). A recent meta-analysis has concluded that CBT-I has a rather blunted effect on objective compared to subjective sleep parameters, but there is an urgent need for more studies using objective sleep measures (Mitchell, Bisdounis, Ballesio, Omlin, & Kyle, 2019). Moreover, since only 60 % of treated patients show a clinically significant response (Morin et al., 2009), it is crucial to examine other therapeutic interventions that could further enhance the CBT-I efficacy.

2. AIMS AND HYPOTHESIS

The aim of this dissertation was to: (a) explore sleep electroencephalographic (EEG) correlates of sleep discrepancy in insomnia; (b) assess whether sleep discrepancy is associated with psychopathology; (c) examine changes of sleep discrepancy during and after the therapy; (d) assess whether the additional chronotherapeutic tool can enhance the effect of CBT-I on sleep parameters. Four studies were conducted to fulfil these goals. The present dissertation is based on four original publications of the author (Janku et al., under review; Janku, Smotek, Farkova, & Koprivova, 2020a, 2020b; Veldova, Buskova, & Koprivova, 2019).

3. SLEEP DISCREPANCY IN DIFFERENT INSOMNIA SUBTYPES (STUDY 1)

Study 1 aimed to compare groups with similar objective sleep continuity parameters according to PSG, which differed in the presence of sleep misperception (PARA vs. good sleeper control group [GS]; PSY vs. PSY/MIS), and to assess sleep EEG correlates of sleep discrepancy (Janku et al., under review).

3.1. Materials and methods

Participants

Study 1 involved 29 patients diagnosed with primary insomnia who underwent a PSG recording in the Prague Psychiatric Centre (now the National Institute of Mental Health; NIMH) between 2011 and 2016, and were retrospectively selected from a database of insomnia patients. Insomnia diagnosis was established according to the 10th edition of the International Classification of Diseases (ICD-10; WHO 2004). Exclusion criteria involved other comorbid sleep disorder, neuropsychiatric disorder present or in the anamnesis, poor-quality PSG records, usage of medication known to affect sleep. Table 1 presents the criteria for distinguishing insomnia subtypes (Perusse et al., 2015).

Group	Objective TST	Sleep discrepancy
PSY	Objective TST < 6 hours	Discrepancy between obj. and subj TST < 60 minutes
PARA	Objective TST ≥ 6 hours	Discrepancy between obj. and subj. TST ≥ 60 minutes
PSY/MIS	Objective TST < 6 hours	Discrepancy between obj. and subj. TST ≥ 60 minutes

Table 1. Criteria for distinguishing insomnia subtypes (Perusse et al., 2015). PSY: Psychophysiological insomnia, PARA: Paradoxical insomnia, PSY/MIS: Psychophysiological insomnia with sleep misperception, TST: Total sleep time.

Participants from the GS group were recruited via internet advertising. Exclusion criteria also included the presence of other sleep or neuropsychiatric disorders. Participants had to be without the usage of medication known to affect sleep. Table 2 summarizes the final sample characteristics.

Group	PSY/MIS	PSY	PARA	GS
n	9	9	11	9
Female/Male	4/5	4/5	4/7	3/6
Mean age	45.89 (14.44)	46.33. (11.47)	35.09 (7.68)	36.22 (15.05)
Length of insomnia (years)	2.32 (2.18)	5.33 (4.05)	3.26 (4.28)	n/a
Education (%)				
High school	44	44	46	56
University degree	56	56	54	44
Married (%)	44	67	36	56

Table 2. Demographic characteristics Sociodemographic characteristics of psychophysiological insomnia with sleep misperception (PSY/MIS), psychophysiological insomnia (PSY), paradoxical insomnia (PARA), and good sleeper control group (GS). Means (SD) are reported.

Full-night PSG

A full-night PSG was recorded from 22:00 (lights-out) to 06:00 (lights-on) by a Brainscope PSG system (Unimedis, Ltd., Czech Republic). All recordings included C3-A2, C4-A1, electrooculography (EOG), electromyography (EMG; submental, mm. tibiales ant.), electrocardiography (ECG), respiratory events, and video monitoring. Experienced raters visually scored the records according to the AASM criteria at 30-second epochs (AASM, 2007).

Self-reported scales and questionnaires

The battery of questionnaires included the Insomnia Severity Index (ISI; Bastien et al., 2001) to portray insomnia difficulties; the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) to assess sleep habits and sleep quality in the preceding two weeks; the Epworth Sleepiness Scale (ESS; Johns 1991) to assess daytime sleepiness; the Beck Depression Inventory-2 (BDI-II; Beck 1996); and the Beck Anxiety Inventory (BAI; Beck and Steer 1993) to assess depression and anxiety symptoms. All subjects evaluated their sleep

subjectively. The misperception index (MI) of total sleep time (TST) was computed (MI = [objective TST – subjective TST] / objective TST) to quantify the degree of sleep discrepancy. The positive MI value reflects the underestimation of TST, while the negative MI value indicates an overestimation of TST, with a value of 0 for perfect estimation (Manconi et al., 2010).

Spectral analysis

Power spectral analysis (PSA) was performed on the sleep EEG during NREM 2, NREM 3, and REM sleep. Due to a retrospective study design, we involved segments of NREM 2 and NREM 3 sleep stages only from the first sleep cycle, and REM sleep segments from the last sleep cycle. The reason for that was to enhance the probability of finding artifact-free segments as there is a higher proportion of NREM sleep during the first half of the night and enhanced REM sleep proportion at the end of the night (Kupfer, 2006; Maes et al., 2014). Fast-Fourier transformation on 2.0-s windows with 1-s overlap (Richards et al., 2013; Welch, 1967), was applied on artifact-free data, and relative power spectra within delta (1-4 Hz), theta (4-7 Hz), alpha (7-11 Hz), sigma (12-16 Hz), beta 1 (14-20 Hz) and beta 2 (20-35 Hz) frequency bands were computed. For the relative PSA, both C3 and C4 channels were used (Perlis, Smith, Andrews, Orff, & Giles, 2001).

3.2. Results

Objective and subjective sleep parameters

As expected, both misperception groups (PSY/MIS, PARA) evaluated their insomnia symptoms as more severe and subjective sleep quality more decreased than their control groups, although they did not differ in objective sleep measures (Tables 3 and 4). In the case of sleep macrostructure, the only common significant difference found in both misperception groups was significantly reduced REM sleep stage. The PARA group also showed a significantly lower NREM 3 and a higher NREM 1 sleep stage proportion compared to the GS group.

	PSY/MIS	PSY	*p*	PARA	GS	*p*
Questionnaires						
ISI	17.44 (3.50)	13.75 (2 .57	**.024**	16.18 (4.09)	4.90 (2.39)	**.000**
PSQI	11.11 (3.35)	9.11 (2.51)	.113	11.36 (2.71)	5.00 (0.45)	**.000**
ESS	7.89 (4.28)	10.44 (5.58)	.489	7.18 (3.01)	10.90 (2.59)	**.020**
BAI	8.67 (4.08)	5.83 (3.62)	.340	6.73 (3.82)	6.20 (3.46)	.882
BDI-II	8.89 (3.11)	6.56 (4.30)	.136	5.73 (3.62)	7.90 (5.96)	.710
Subjective sleep measure						
SOL (min)	152.22 (42.11)	41.67 (32.92)	**.000**	59.00 (41.57)	26.67 (13.54)	**.000**
TST (min)	174.44 (30.23)	322.22 (36.31)	**.000**	264.55 (91.19)	376.67 (40.28)	**.010**
NWAKE	3.00 (1.33)	4.44 (2.74)	.297	5.09 (4.01)	4.33 (1.15)	.378
SE %	44.31 (9.56)	71.00 (9.02)	**.000**	54.41 (18.65)	89.67 (4.62)	**.000**
MI	0.40 (0.09)	- 0.15 (0.28)	**.000**	0.35 (0.26)	0.04 (0.09)	**.000**

Table 3. Differences in subjective sleep parameters and daytime symptoms between insomnia patients and good sleepers. Subjective sleep parameters: means (SD) in psychophysiological insomnia with sleep misperception (PSY/MIS), psychophysiological insomnia (PSY), paradoxical insomnia (PARA), and good sleepers (GS). Results of the Mann-Whitney test are reported. Bold indicates a statistically significant result ($p \leq 0.05$). ISI: Insomnia Severity Index, PSQI: Pittsburgh Sleep Quality Index, ESS: Epworth Sleepiness Scale, BAI: Beck Anxiety Inventory, BDI: Beck Depression Inventory SOL: sleep onset latency, TST: total sleep time, NWAKE: number of awakenings, SE: sleep efficiency, MI: misperception index.

	PSY/MIS	PSY	*F*	*p*	PARA	GS	*F*	*p*
SOL (min)	26.97 (14.27)	26.48 (26.79)	.502	.490	12.50 (5.74)	16.13 (9.92)	.583	.456
TST (min)	289.78 (34,29)	296.22 (58.50)	.676	.424	410.50 (30.48)	398.06 (27.13)	.505	.487
NWAKE	41.78 (15.22)	37.85 (23.14)	1.873	.191	23.35 (10.04)	13.44 (7.47)	1.908	.185
WASO %	29.00 (0.09)	25.16 (0.13)	1.932	.185	8.43 (0.03)	6.23 (0.05)	1.148	.299
SE %	71.00 (0.09)	74.71 (0.13)	1.932	.185	91.57 (0.03)	93.77 (0.05)	1.148	.299
NREM1 %	15.76 (0.05)	13.24 (0.05)	1.391	.257	8.28 (0.03)	2.47 (0.01)	20.603	**.000**
NREM2 %	34.43 (0.09)	38.88 (0.14)	.444	.515	45.22 (0.07)	49.81 (0.05)	3.311	.086
NREM3 %	12.02 (0.06)	10.06 (0.05)	1.200	.291	16.80 (0.05)	24.09 (0.07)	4.739	**.044**
REM %	7.31 (0.04)	12.18 (0.05)	5.600	**.032**	15.96 (0.05)	21.73 (0.04)	5.524	**.031**

Table 4. Differences in objective sleep parameters in insomnia patients and good sleepers control group. Objective sleep parameters: means (SD) in psychophysiological insomnia with sleep misperception (PSY/MIS), psychophysiological insomnia, (PSY), paradoxical insomnia (PARA), and good sleepers (GS). Results of the ANCOVA analysis are reported. Bold indicates a statistically significant result ($p \leq 0.05$). SOL: sleep onset latency, TST: total sleep time, NWAKE: number of awakenings, WASO: wake after sleep onset, SE: sleep efficiency, NREM: non-rapid eye movement sleep, REM: rapid eye movement sleep.

Sleep EEG activity

Comparison analyses revealed no differences in relative spectral power during sleep between the groups. However, delta EEG activity during NREM 3 sleep tended to be lower in the PSY/MIS compared to the PSY group ($F = 4.789$; $p = .056$).

Correlates of sleep discrepancy

Linear regression analyses revealed a significant negative relation between proportion of REM sleep and MI ($\beta = -0.36$; $p = .016$) and positive relation to subjective TST ($\beta = 0.78$; $p <. 000$) in the whole sample. After the exclusion of the GS control group, the negative correlation between REM proportion and MI did not remain significant ($\beta = -0.34$; $p = .091$). Nevertheless, the relation between REM proportion and subjective TST was still significant ($\beta = 0.69$; $p < .000$).

	PSY/MIS	PSY	*F*	*p*	PARA	GS	*F*	*p*
NREM 2								
Delta	0.58 (0.11)	0.63 (0.12)	.068	.800	0.61 (0.12)	0.62 (0.08)	.004	.951
Beta 1	0.04 (0.02)	0.04 (0.04)	.020	.890	0.05 (0.03)	0.05 (0.02)	.258	.618
Beta 2	0.03 (0.03)	0.01 (0.01)	1.397	.267	0.03 (0.04)	0.03 (0.03)	.571	.460
NREM 3								
Delta	0.71 (0.11)	0.75 (0.10)	4.789	.056	0.77 (0.08)	0.77 (0.07)	.011	.918
Beta 1	0.02 (0.01)	0.01 (0.01)	.016	.901	0.02 (0.01)	0.02 (0.01)	.008	.931
Beta 2	0.01 (0.01)	0.01 (0.00)	1.175	.307	0.01 (0.01)	0.01 (0.01)	1.815	.196
REM								
Delta	0.5 (0.13)	0.58 (0.12)	2.759	.131	0.53 (0.1)	0.55 (0.08)	.324	.577
Beta 1	0.05 (0.02)	0.04 (0.02)	.021	.889	0.05 (0.04)	0.05 (0.01)	.192	.667
Beta 2	0.04 (0.01)	0.03 (0.01)	.627	.449	0.06 (0.08)	0.04 (0.02)	.319	.579

Table 5. Differences in sleep EEG activity during NREM and REM sleep. Power spectral analysis: mean values (SD) of relative powers at central sites in psychophysiological insomnia with sleep misperception (PSY/MIS). Psychophysiological insomnia (PSY), paradoxical insomnia (PARA), and good sleepers (GS) in NREM 2, NREM 3, and REM sleep stages; ANCOVA results are presented. NREM: non-rapid eye movement sleep, REM: rapid eye movement sleep. Relative power was computed as the power within a frequency band (in μV2/Hz) divided by the power across all frequencies (1-35 Hz) (also in μV2/Hz).

4. SLEEP DISCREPANCY IS RELATED TO DEPRESSIVE SYMPTOMS IN INSOMNIA PATIENTS (STUDY 2)

Study 2 aimed to answer the question of whether insomnia patients with depressive symptoms show a higher degree of sleep discrepancy compared to insomnia patients without depressive symptoms. The second aim was to explore the relation between REM sleep proportion, sleep discrepancy, and depressive symptoms.

4.1. Materials and methods

Participants

Participants were retrospectively selected from a database of 141 insomnia patients who completed one night of PSG at the NIMH, Czech Republic,

between the years 2016 and 2019. Patients were diagnosed with insomnia by physicians, according to the ICD-10 (WHO, 2004). The inclusion criteria were: (a) age 18 to 70; (b) absence of severe comorbid psychiatric, neurological or somatic disease; (c) no usage of medication affecting sleep. Exclusion criteria were (a) night shifts; (b) age over 70 years.

Self-reported scales and questionnaires

Questionnaires included BDI-II, BAI, and ESS. Based on established cut-off scores (A. T. Beck, Steer, R. A., Brown, G.K., 1996), different severity of depressive symptoms was evaluated. All patients answered questions about the subjective sleep quality of the previous night in the sleep laboratory. The MI of TST was computed.

Full-night PSG

All whole-night PSG recordings included EEG according to the 10/20 standard system, EOG, EMG (three submental electrodes), ECG, and video monitoring. Data were recorded using Brainscope polysomnography system (M&I spol. s.r.o., Czech Republic). The records were visually scored by experienced clinicians, according to the American Academy of Sleep Medicine criteria at 30-second epochs (AASM, 2007).

4.2. Results

Participants

Eighty-eight patients with insomnia fulfilling the inclusion criteria were included in the final analysis. We further divided the sample into two groups according to the established cut-off score of BDI-II, distinguishing minimal and mild depressive symptoms: (1) insomnia without depressive symptoms (BDI-II $\leq$ 13; INS); (2) insomnia with depressive symptoms (BDI-II > 13; INS-D). The total sample and the two subgroups characteristics are presented in Table 6.

	Total sample	INS	INS-D	$t / \chi 2 / U$	P-value
N	88	46	42		
Age †	40.29 (14.09)	44 (14.23)	38.78 (12.68)	1.808	.074
Sex, female (%)	47.4	39.13	54.76	2.156	.142
BDI-II ¥	13.57 (9.92)	6.28 (4.26)	21.57 (7.99)	0.000	**.000**
BAI ¥	10.72 (9.71)	6.84 (9.71)	14.97 (7.81)	337	**.000**
ESS †	8.75 (5.4)	7.73 (4.93)	9.75 (5.74)	-1.765	.081
Anxiety severity based on BAI (n):					
Minimal anxiety	35	28	7	17.908	**.000**
Mild anxiety	15	17	14	0.587	.443
Moderate anxiety	13	0	13	16.706	**.000**
Severe anxiety	6	1	5	3.272	.070

Table 6. Clinical and sleep characteristics of the total sample, INS, and INS-D group. Results of independent t-tests, chi-squared test, and Mann-Whitney U test are presented. Bold indicates a statistically significant result ($p \leq 0.05$). INS: insomnia patients without depressive symptoms, INS-D: insomnia patients with depressive symptoms, BDI-II: Beck Depression Inventory, BAI: Beck Anxiety Inventory, ESS: Epworth Sleepiness Scale. † Results of independent t-tests are presented. ¥ Results of the Mann-Whitney U test are presented.

Subjective and objective sleep characteristics

Only a difference in subjective TST was close to the significance threshold, indicating shorter subjective TST in the INS-D group. A significantly higher MI TST was observed in the INS-D compared to the INS group (Table 7).

	Total sample	INS	INS-D	t / U	P-value
Subjective sleep parameters					
SOL (min.) ¥	57.59 (48.39)	57.06 (55.16)	60.33 (42)	641.5	.307
TST (min.)	305.65 (125.63)	323.97 (112.67)	272.19 (132.61)	1.944	.055
SE (%)	63.36 (30.69)	65.18 (28.51)	57.2 (32.42)	1.164	.248
Polysomnography					
SOL (min.) ¥	28.32 (35.02)	28.437 (31.07)	29.43 (38.6)	957	.805
TST (min.) ¥	352.91 (88.52)	351.88 (76.03)	344.31 (102.29)	973	.908
WASO (%) ¥	18.98 (15.83)	17.64 (10.41)	21.32 (20.97)	970	.889
SE (%) ¥	80.86 (15.3)	81.24 (12.71)	79.53 (18.67)	956.5	.802
REM (%)	16.09 (6.79)	16.86 (6.5)	15.45 (7.25)	0.968	.336

REM sleep latency (min.)	114.93 (62.41)	124.79 (69.73)	103.09 (54.25)	1.593	.115
NREM 1 (%) ¥	5.94 (3.25)	6.27 (3.37)	5.58 (3.31)	893	.44
NREM 2 (%)	42.99 (10.92)	43.66 (10.16)	41.94 (12.34)	0.72	.473
NREM 3 (%)	17.45 (6.52)	16.93 (6.17)	17.32 (6.48)	-0.285	.775
MI TST	0.14 (0.31)	0.07 (0.31)	0.23 (0.3)	-2.389	**.019**

Table 7. Objective and subjective sleep measures in the total sample, INS, and INS-D groups. Results of the independent t-tests are presented. Bold indicates a statistically significant result *(*$p \leq 0.05$).INS: insomnia patients without depressive symptoms, INS-D: insomnia patients with depressive symptoms, SOL: sleep onset latency, TST: total sleep time, WASO: wake after sleep onset, SE: sleep efficiency, REM: rapid eye movement, NREM: non-rapid eye movement, MI: Misperception Index. ¥ Results of the Mann-Whitney U test are presented.

Correlations

A significant positive correlation was found between the BDI-II score and MI TST, $r_s = .267$, p = .013. Because of the higher degree of anxiety symptoms in the INS-D group compared do INS, we also explored whether the BAI score is related to the MI TST. No significant relationship was observed, $r_s = .175$, p = .109. There was a significant negative correlation between REM sleep proportion and MI TST, $r = -.346$, p = .001. The BDI-II score was not significantly related to REM sleep proportion, $r_s = -.12$, p = .265.

5. SLEEP DISCREPANCY DURING AND AFTER CBT-I (STUDY 3)

Study 3 aimed to explore changes in sleep discrepancy after CBT-I in adults with insomnia. Moreover, we aimed to assess changes in TST discrepancy during the entire therapeutic programme. Another objective was to assess the effect of CBT-I in two insomnia subgroups differing in sleep perception (Janku et al., 2020b).

5.1. Materials and methods

Participants

Fifty patients with insomnia were recruited at the Department of Sleep Medicine of the NIMH, Czech Republic, and enrolled in the CBT-I group programme. Insomnia diagnosis was established according to the ICD-10

(WHO 2004). Inclusion criteria involved: (a) a minimum age of 18; (b) absence of severe comorbid psychiatric, neurological or somatic disease; (c) motivation to complete the CBT-I programme; (d) no or stable use of medication affecting sleep. Exclusion criteria were: (a) discontinued CBT-I programme; (b) previous experience with CBT-I without effect; (c) night shift employment.

Self-reported measures

At the beginning and at the end of the CBT-I programme, all patients completed a battery of questionnaires: ISI; ESS; the Hyperarousal Scale (HAS), empirically designed to measure daytime alertness, reflecting the enhanced arousal with the cut-off score > 40 (Regestein, Dambrosia, Hallett, Murawski, & Paine, 1993); and a modified version of the brief World Health Organization Quality of Life questionnaire (QOL; Harper et al., 1998). Patients were asked to complete a sleep diary every day during the six weeks of therapy.

Actigraphy

For the current study, the MotionWatch 8 (CamNtech Ltd., Cambridge, UK) actigraphic watch was used for objective measurement of sleep. Patients received the devices at the beginning of CBT-I and wore them on their non-dominant wrist continuously for six consecutive weeks. The data were downloaded and analysed using MotionWare 1.4 software. MI TST was calculated. Sleep onset latency (SOL) and wake after sleep onset (WASO) discrepancies were obtained by computing the difference between self-reported SOL/WASO and objective SOL/WASO (Herbert et al., 2017). Negative values reflect self-reported underestimation compared to objective measures, whereas positive values represent overestimation compared to objective findings.

CBT-I

The CBT-I lasted for six weeks and consisted of one 2-hour session per week, with a maximum of eight patients per group. Each session had a specific structure according to the recommendations of the clinical manual for insomnia treatment (Morin and Espie, 2003). The first week of therapy occurred without intervening in patients' sleep schedules and thus served as a baseline. Sleep restriction was implemented in Week 2. Patients were allowed to spend the same amount of time in bed as their average TST during the previous week. The minimum length was set at 5 h. The sleep window was titrated every week, according to average sleep efficiency (SE% = TST/total time in bed). If the SE

was 85% or higher, then the time in bed was prolonged by 15 min. Otherwise, time remained the same for another week. Psychoeducation was provided at the beginning of each session. Stimulus control therapy was set up in Week 3. The recommendations involved the following: (a) leaving the bed if one cannot fall asleep within 20 min, performing a pleasant and relaxing activity in a different room, and coming back to bed when feeling sleepy; (b) avoiding naps; (c) only using the bed and bedroom for sleep and sex. The last three sessions mainly focused on cognitive therapy (identification and reduction of dysfunctional beliefs about sleep, insomnia, and its consequences).

5.2. Results

Participants

Since no validated quantitative criteria for sleep misperception exists (Castelnovo et al., 2019), we have divided the sample into two groups based on their MI to distinguish patients who underestimated sleep quantity (Manconi et al., 2010). The first group consisted of patients who underestimated their TST (MI > 0; i.e., the underestimating [UN] group). The second group comprised patients with accurate sleep perception or with a tendency to overestimate TST (MI ≤ 0; accurate/overestimating [A/O] group). Data from 36 participants were included in the final analyses. Sociodemographic and clinical characteristics are summarized in Table 8.

At baseline, the UN group subjectively estimated sleep parameters as significantly worse than the A/O group, whereas the groups did not differ significantly in most of the objective sleep parameters. The only difference was found in objective SE, which was higher in the UN group. Significantly higher discrepancies were observed in the UN group compared to A/O group.

	Total sample (n = 36)	UN group (n = 16)	A/O group (n = 20)	$t / \chi 2$	p
Sex, % female	61	75	50	2.338	.126
Age (mean, SD) †	46.7 (13.9)	46.2 (11.8)	47.1 (15.8)	-0.181	.857
Length of insomnia (mean years, SD) †	5.92 (5.34)	6.39 (5.21)	5.38 (5.63)	0.513	.612
Insomnia symptoms (n):					
Sleep onset problems	7	2	5	1.036	.309
Sleep continuity problems	15	7	8	0.010	.922
Waking up earlier than desired	1	1	0	1.222	.269
Combination	12	6	6	0.135	.713
Insomnia severity according to ISI (n):					
Mild insomnia	10	4	6	0.283	.595
Moderate insomnia	22	8	14	0.971	.324
Severe insomnia	4	4	0	5.100	**.024**
Significant daytime sleepiness based on ESS (n)	5	2	3	0.117	.732
Significant hyperarousal based on HAS (n)	14	6	8	0.169	.681
Comorbidities (n):					
Depressive symptoms	7	5	2	0.009	.925
Anxiety symptoms	2	2	0	1.694	.193
Tinnitus	2	2	0	0.655	.418
Hypertension	5	4	1	2.973	.085
Thyroid disease	3	2	1	0.655	.418
Married (%)	50	50	45	0.330	.566
Education (%):					
Secondary school	39	44	35		
University degree	61	56	65	0.139	.710

Table 8. Sociodemographic and clinical characteristics of the total sample and the two subgroups.Results of independent-samples t-tests and Chi-squared test are presented. Bold indicates a statistically significant result ($p \leq 0.05$). UN Group: Underestimating group, A/O Group: Accurate/overestimating group, ISI: Insomnia Severity Index, ESS: Epworth Sleepiness Scale, HAS: Hyperarousal Scale.† Results of independent t-test

Changes in sleep and daytime symptoms in the total sample after CBT-I

After CBT-I, there was a significant decrease of insomnia severity from moderate to mild insomnia (Bastien et al., 2001), decreased subjective

hyperarousal and increased quality of life after the treatment. CBT-I was associated with a significant reduction of subjective SOL and WASO, and a higher subjective SE, with no change in self-reported TST. In case of objective parameters, both SOL and TST were significantly reduced after the therapy. There was no change in objective SE and WASO. The MI of TST was found to vary across the weeks of treatment, $F(5, 170) = 11.79$, $p < .001$. No significant change was observed between Week 1 (-0.01, SD = 0.16) and Week 2 (-0.07, SD = 0.16, $p = .13$) when the sleep restriction was implemented in the total sample. Visual presentation of MI TST changes in the total sample throughout the treatment is shown in Figure 1.

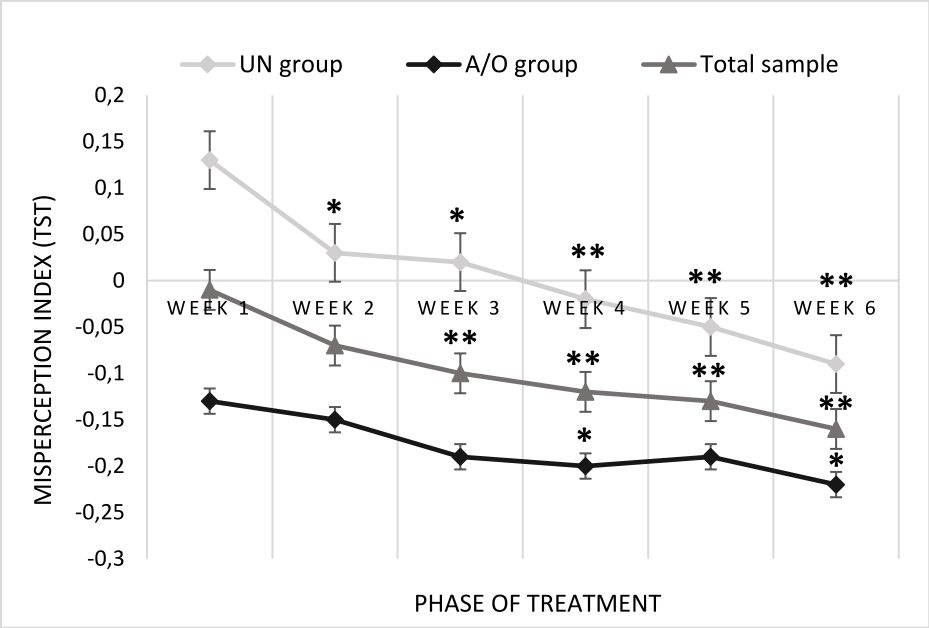

Figure 1. Changes of MI TST (mean) during the CBT-I in the total sample, UN group, and A/O group.TST: total sleep time, UN group: Underestimating group, A/O group: Accurate/overestimating group $^{*}p \leq 0.05$, $^{**}p \leq 0.01$ for comparison with Week 1.

Effect of CBT-I in the UN and A/O group

No significant Time x Group interaction was found in any of the questionnaires. Participants in both groups reported significantly lower insomnia severity as well as lower self-reported hyperarousal and significantly

higher quality of life after the treatment, without a significant change in daytime sleepiness. A significant Time x Group interaction was found in sleep parameters (Table 9). Only the UN group showed significantly higher self-reported SE and lowered self-reported WASO after the therapy, as well as shorter objective TST and lower SOL discrepancy. Both groups reported a significant change of TST discrepancy after CBT-I and no change in WASO discrepancy (Table 10).

The MI of TST varied across the weeks of treatment in the UN group, $F(5, 70) = 12.44$, $p < .001$, with a significant decrease from Week 1 (+0.14, SD = 0.08) to Week 2 (+0.02, SD = 0.15, $p = .048$). In the A/O group, MI TST also varied across the therapy, $F(5, 95) = 2.93$, $p < .05$, without a significant change of MI TST from Week 1 (-0.13, SD = 0.09) to Week 2 (-0.15, SD = 0.13, $p = .99$). Changes of MI TST during the CBT-I are visualized in Figure 1.

Condition	*Pre-treatment*	*Post-treatment*	*Main effects*	*df*	*F*	*p*	*ES (η^2)*
Sleep diary							
SOL (min.)							
UN group	51.00 (34.53)	23.15 (5.33)	Time	1, 31	21.953	**.000**	**.415**
A/O group	33.11 (20.62)	16.80 (7.38)	Group		5.550	**.025**	**.152**
			Time X Group		1.497	.230	.046
TST (min.)							
UN group	330.56 (58.38)	334.7 (37.2)	Time	1, 34	0.999	.325	.029
A/O group	388.40 (46.70)	397.30 (37.60)	Group		19.072	**.000**	**.359**
			Time X Group		0.134	.726	.004
SE (%)							
UN group	67.1 (7.9)	83.5 (7.9)	Time	1, 31	47.766	**.000**	**.606**
A/O group	80 (6.3)	88.2 (6.7)	Group		20.268	**.000**	**.395**
			Time X Group		4.362	**.045**	**.123**

WASO (min.)							
UN group	61.00 (49.25)	30.69 (23.04)	Time	1, 31	12.446	**.001**	**.286**
A/O group	28.27 (22.08)	20.65 (13.91)	Group		6.510	**.016**	**.174**
			Time X Group		4.453	**.043**	**.126**
Actigraphy							
SOL (min.)							
UN group	11.6 (8.8)	8.5 (11.8)	Time	1, 34	7.681	**.009**	**.184**
A/O group	17.8 (15.1)	9.1 (7.4)	Group		1.202	.281	.034
			Time X Group		1.754	.194	.049
TST (min.)							
UN group	372.7 (33.5)	316.3 (36.8)	Time	1, 32	39.220	**.000**	**.551**
A/O group	347.7 (43.4)	330.3 (35.8)	Group		0.168	.685	.005
			Time X Group		11.370	**.002**	**.262**
SE (%)							
UN group	77.3 (4.7)	77.8 (4.8)	Time	1, 34	1.119	.297	.032
A/O group	71.9 (5.9)	73.2 (4.8)	Group		11.034	**.002**	**.245**
			Time X Group		0.158	.694	.005
WASO (min.)							
UN group	97.57 (26.07)	72.60 (11.27)	Time	1, 31	8.069	**.008**	**.207**
A/O group	108.68 (35.24)	102.88 (18.64)	Group		8.751	**.006**	**.220**
			Time X Group		3.134	.087	.092

Table 9. Pre- to post-treatment differences in objective and subjective sleep parameters in the UN and A/O group. Results of two-way mixed ANOVA and partial eta square (η^2) for effect size are presented, means (SD). Bold indicates a statistically significant result ($p \leq 0.05$). UN group: Underestimating group, A/O group: Accurate/overestimating group. SOL: sleep onset latency,

TST: total sleep time, SE: sleep efficiency, WASO: wake after sleep onset, MI: misperception index, ES: effect size.

Condition	*Pre-treatment*	*Post-treatment*	*Main effects*	*df*	*F*	*p*	*ES (η^2)*
SOL discrepancy (min.)							
UN group	34.75 (34.52)	15.96 (13.38)	Time	1, 34	68.775	**.000**	**.669**
A/O group	15.29 (20.58)	7.67 (10.12)	Group		6.253	**.017**	**.155**
			Time X Group		11.904	**.002**	**.259**
WASO discrepancy (min.)							
UN group	-41.35 (48.92)	-49.64 (17.63)	Time	1, 30	0.475	.496	.016
A/O group	-80.71 (38.95	-83.73 (20.29)	Group		13.242	**.001**	**.306**
			Time X Group		0.072	.790	.002
TST discrepancy (MI)							
UN group	0.13 (0.1)	-0.1 (0.1)	Time	1, 34	8.816	**.005**	**.206**
A/O group	-0.13 (0.1)	-0.2 (0.1)	Group		37.122	**.000**	**.522**
			Time X Group		1.572	.219	.044

Table 10. Pre- to post-treatment differences in objective and subjective sleep discrepancy parameters in UN and A/O group.Results of two-way mixed ANOVA and partial eta square (η^2) for effect size are presented, means (SD). Bold indicates a statistically significant result ($p \leq 0.05$). UN group: Underestimating group, A/O group: Accurate/overestimating group. SOL: sleep onset latency, TST: total sleep time, WASO: wake after sleep onset, MI: misperception index, ES: effect size.

6. EFFECT OF CBT-I AND BLUE LIGHT-BLOCKING GLASSES ON SLEEP DISCREPANCY (STUDY 4)

Following recent research (Shechter, Kim, St-Onge, & Westwood, 2018), the aim of this randomized controlled trial was to for the first time to assess the effect of CBT-I in combination with blue-light blocking glasses to explore whether the additional chronotherapeutic intervention could enhance an impact

of CBT-I on sleep parameters by reducing negative impact of artificial light on sleep, and promoting circadian regulation. (Janku et al., 2020a).

6.1. Materials and methods

Participants

Forty-five patients with chronic insomnia who were enrolled in the CBT-I group programme were invited to participate in the present study. Insomnia diagnosis was established on the ICD-10 (WHO, 2004). Inclusion and exclusion criteria were the same as for Study 3.

Self-reported and objective sleep measures

Patients were asked to complete a sleep diary every day during the CBT-I programme and to completed a battery of questionnaires to assess sleep complaints and daytime symptoms at the beginning and the end of CBT-I. The battery included PSQI (Buysse et al., 1989); ISI; and HAS. Actigraphy recording was based on the same methodology as in the Study 3. The MI TST and the SOL and WASO discrepancy parameters were obtained (Herbert et al., 2017).

Interventions

The CBT-I group programme had the same structure as in Study 3. For the active condition, the UVEX S1933X (U.S. certification ANSI Z87+ and CSA Z94.3) orange glasses were given to patients. Based on the used spectrum control technology, they were supposed to reduce up to 98 % of lights of blue wavelength. As the placebo condition, the UVEX S1900 (U.S. certification ANSI Z87+ and CSA Z94.3) clear glasses with no ability to filtrate blue light were used. The patients reported no adverse effects.

Procedure

At the first CBT-I session, participants were asked to fill in the questionnaires, sleep diary and received actigraphs. The first week served for baseline measurement. In the second session, patients received either active glasses or placebo glasses. Patients in one group had the same type. They were told that the study is focused on several types of glasses with different filtration properties. The instruction was to wear the glasses every day of the treatment at least 90 minutes before bedtime. To increase compliance, patients were

repeatedly educated about light hygiene and were asked to report usage of glasses in sleep diaries every day.

6.2. Results

A final sample of 30 participants was involved in the analyses. Basic characteristics are summarized in Table 11. A difference in age reached the threshold of statistical significance [$t(28) = -2.052$, $p = 0.050$] and was used as a covariate in further analyses together with gender and assigned therapist. In baseline measures, the only statistically significant difference between the active and placebo group was found for sleepiness, with a higher ESS score found in the active group compared to the placebo group. Despite significance, the value was well below the cut-off score for clinically relevant sleepiness in both groups (Johns, 1991).

	Total sample	Active group	Placebo group
n	30	15	15
Female / Male	15 / 15	6 / 9	9 / 6
Age	48.1 (16.1)	42.4 (14.8)	53.9 (15.8)
Length of insomnia (years)	5.32 (5.07)	6.33 (6.62)	4.38 (2.68)
Married (%)	50 %	46 %	53 %
Education (%):			
High school	26 %	15 %	36 %
University degree	74 %	85 %	64 %

Table 11. Sociodemographic characteristics of participants in CBT-I groups.

Effect of therapeutic intervention in Active and Placebo group

After the therapy, a significant difference was found for the ISI, PSQI, and subjective WASO and SE in both groups. In the active group only, a significant reduction was observed in the HAS score and prolongation of subjective TST. In the placebo group, a significant reduction of objective TST was observed. A significant change of MI TST and a reduction of SOL discrepancy was present only in the active group (Table 12).

Sleep parameter	*Pre-treatment*	*Post-treatment*	*P-value*	*ES*	*Sleep parameter*	*Pre-treatment*	*Post-treatment*	*P-value*	*ES*
Questionnaires					**Questionnaires**				
HAS	41.60 (8.40)	36.93 (10.02)	**.012**	**0.75**	**HAS**	35.5 (10.13)	32.08 (11.28)	.233	0.36
Sleep diaries					**Sleep diaries**				
SOL (min.)	36.80 (27.01)	18.41 (6.15)	**.021**	**0.73**	**SOL (min.)**	59.77 (62.30)	25.48 (23.53)	.058	0.56
TST (min.)	369.14 (48.93)	406.02 (50.16)	**.018**	**-0.76**	**TST (min.)**	382.73 (69.27)	375.69 (49.32)	.588	0.15
WASO (min.)	43.95 (41.94)	20.63 (11.81)	**.049**	**0.61**	**WASO (min.)**	43.78 (30.64)	30.83 (22.92)	**.034**	**0.63**
SE (%)	74.59 (12.63)	90.09 (4.28)	**.001**	**-1.21**	**SE (%)**	74.67 (11.30)	85.09 (9.07)	**.002**	**-1.02**
Actigraphy					**Actigraphy**				
SOL (min.)	12.47 (15.12)	8.83 (9.83)	.117	0.43	**SOL (min.)**	18.12 (12.31)	12.31 (11.74)	.115	0.47
TST (min.)	359.97 (52.18)	350.22 (47.50)	.329	0.26	**TST (min.)**	378.79 (49.46)	352.13 (37.17)	**.024**	**0.72**
WASO (min.)	100.78 (26.54)	94.33 (29.35)	.339	0.34	**WASO (min.)**	112.45 (33.24)	102.46 (31.60)	.140	0.44
SE (%)	74.53 (6.21)	75.74 (5.67)	.254	-0.31	**SE (%)**	73.68 (5.47)	74.95 (5.99)	.161	-0.41
Sleep discrepancy					**Sleep discrepancy**				
MI TST	-0.05 (0.17)	-0.16 (0.06)	**.018**	**0.76**	**MI TST**	-0.05 (0.23)	-0.09 (0.13)	.212	0.38
SOL (min.)	24.33 (23.88)	8.5 (10.97)	**.037**	**0.65**	**SOL (min.)**	25.98 (40.65)	17.42 (24.62)	.213	0.38
WASO (min.)	-58.54 (49.65)	-75.11 (33.44)	.186	0.38	**WASO (min.)**	-73.66 (45.01)	-70.93 (33.23)	.863	0.05

Table 12. Effect of intervention within each group. Results of the paired-samples t-tests are presented for a group with "active" filtering glasses and "placebo" glasses. *t*-values, statistical significance, and effect sizes (Cohen's *d*) are provided. Bold indicates a statistically significant result ($p \leq 0.05$). ISI: Insomnia Severity Index, PSQI: Pittsburgh Sleep Quality Index, HAS: Hyperarousal Scale, SOL: Sleep Onset Latency, TST: Total Sleep Time, WASO: Wake After Sleep Onset, SE: Sleep Effectivity.

7. DISCUSSION

Our results highlight the role of REM sleep in the subjective evaluation of sleep duration and its underestimation in insomnia patients. Both PSG studies

showed a significant association between a reduction of REM sleep proportion and a degree of sleep misperception. A lower proportion of REM sleep was also the only common feature found in both sleep misperception groups. REM sleep could contribute to more accurate estimates of sleep duration because of vivid and emotional dreams, which are easier to remember (Perusse et al., 2015). Thus, one could better distinguish between sleep and a state of wakefulness. A study by Mercer and Lack (2003) showed that patients with insomnia perceived their sleep better when they were awakened from REM sleep than from the NREM sleep period. Increased NREM 1 and decreased NREM 3 sleep stage found in PARA compared to GS, are in line with previous studies showing alterations in different sleep parameters than in conventional sleep continuity measures (Bastien, Lebel, & Gaucher, 2014) in insomnia with sleep discrepancy.

A greater sleep discrepancy was connected with more severe depressive symptoms, which is in line with previous studies (Tsuchiyama, Nagayama, Kudo, Kojima, & Yamada, 2003). It has been documented in both patients with depression (Mathews & Bradley, 1983) and a non-clinical sample with induced depressive mood (Matt, Vazquez, & Campbell, 1992) that a current mood state may influence an individual's memory recalls or information processing. Patients with depressive mood might be more prone to evaluate their sleep as worse than it is according to the objective measures in order to be congruent with their current mood. Another possible explanation is related to the assumption that the sleep discrepancy reflects objective sleep alterations associated with specific brain regions and sleep stages that may cause a mood disruption. Both insomnia and depression have been linked to increased cortical arousal during sleep (Hein et al., 2017) and altered REM sleep (Riemann et al., 2012). The REM sleep stage is crucial for emotion regulation processes, which are suggested to be impaired in insomnia and especially in depression. As such, the emotion dysregulation has been proposed as another factor that may underlie the link between these two syndromes (Baglioni, Spiegelhalder, Lombardo, & Riemann, 2010). Our analyses did not reveal a difference in REM sleep proportion between the groups, nor did we found the relation between the REM sleep proportion and depression severity. However, other alterations of the REM sleep stage could be involved, such as REM sleep disruption by arousals (Wassing et al., 2019).

Studies on CBT-I revealed a significant reduction of sleep quantity underestimation after the therapy. In Study 3, objective TST was significantly reduced with no change in subjective TST, leading to an overestimation of

objective TST. The reduction of objective TST after CBT-I has been reported in previous studies (Edinger, Wohlgemuth, Radtke, Coffman, & Carney, 2007) as a possible consequence of sleep restriction (Kyle et al., 2014). In line with our hypotheses, the UN group reported a significant decrease in TST discrepancy as well as in SOL discrepancy, which is in accordance with previous research (Cronlein et al., 2019). Sleep discrepancies could have been affected by several CBT-I components. In the UN group, the change of TST misperception could have been caused by a significant shortening of objective sleep duration after CBT-I as a consequence of sleep restriction (Kyle et al., 2014). This assumption was further supported by a significant change of TST discrepancy from Week 1 to Week 2 when the sleep restriction was implemented. Due to the subjective underestimation of sleep duration in the UN group at the beginning of treatment, this group could have a stricter sleep window, leading to an increased sleep pressure, more consolidated sleep (Kyle et al., 2014), and the subsequent correction of sleep misperception. Psychoeducation and cognitive therapy have been shown to reduce dysfunctional beliefs about sleep, and these changes have been associated with improvements in objective and subjective sleep quality (Edinger, Wohlgemuth, Radtke, Marsh, & Quillian, 2001). Thus hypothetically, cognitive therapy could have contributed to the overestimation of TST in the A/O group after the therapy in the present study. However, any conclusions cannot be made since we did not involve the measurement of cognition.

Study 4 showed that the additional chronotherapeutic tool might enhance the effect of CBT-I on subjective sleep quality, which is in accordance with a previous study (Shechter et al., 2018). Only the group with active glasses showed a significant change in TST discrepancy and a significant reduction in SOL discrepancy. In addition, this therapeutic combination was associated with no change in objective TST, which was reduced in the placebo group, similarly as in Study 3. Hypothetically, the blue-light blocking glasses could help to maintain the objective TST and alleviate this effect of sleep restriction.

Studies have shown that evening exposure to blue-light usually emitted from electronic devices may cause a suppressed secretion of melatonin (Brainard et al., 2015), and decreased overall subjective sleep quality (Gronli et al., 2016). The blue-light blocking glasses may have, therefore, weakened the negative effect of blue-light exposure on sleep parameters. The active glasses might have also reduced the effect of light on arousal, which could consequently improve sleep quality. A short-wavelength spectrum of light at night has been related to enhanced cortical arousal (Smotek, Vlcek, Saifutdinova, &

Koprivova, 2019). In line with this assumption, subjectively evaluated hyperarousal was significantly reduced only in the group with active glasses in our study, which could have reflected a reduction in cognitive arousal (van der Lely et al., 2015). Decreased arousal might have led to a decreased subjective SOL and reduction in SOL discrepancy as well as prolonged subjective TST and the shift towards overestimation of sleep duration in the active group.

The results of the present thesis should be interpreted with caution in light of its limitations. Because of the retrospective study design in Study 1 and Study 2, we could not implement an adaptation PSG night. This might have had an impact on sleep parameters, especially on the PSA results in the GS group. Another limitation is a small number of participants in Study 1. This was caused by the fact that we only included patients who underwent PSG, which is not usually indicated for insomnia patients in clinical practice, as well as because we aimed to involve patients who did not take any medication, which might influence their sleep EEG. Another limitation was that we did not compare PSY/MIS, PARA, and GS groups because of the large age differences. Also, the comparison of PARA and GS could be biased by the fact that GS did not complain about poor sleep and did not have a diagnosis of insomnia. However, we were able to detect a similar change of REM sleep in both PSY/MIS (compared to PSY) and PARA (compared to GS), further supporting the suggestion of an important role of REM sleep in subjective sleep evaluation. Moreover, sleep misperception may also occur in healthy subjects (Bianchi, Wang, & Klerman, 2012). The limitation in Study 2 was related to the measurement of depression symptoms only by a self-reported questionnaire and not by an objective assessment by a psychiatrist. Therefore, it might not reflect the real severity of reported symptoms. One of the limitations of Study 3 and 4 was the absence of a control group of patients undergoing a different type of treatment or remaining untreated. Thus, we cannot conclude with certainty that the observed effect was associated only with CBT-I. Study 4 would greatly benefit from the control of daytime light exposure of patients, which could have mediated the effect of evening light exposure (Rangtell et al., 2016). Additionally, the potential role of chronotype or light hygiene before the CBT-I treatment was not explored.

8. SUMMARY AND CONCLUSION

The findings are in line with the assumption that insomnia patients with sleep discrepancy show specific sleep alterations, highlight the importance of

REM sleep in subjective evaluation of sleep, point out the association between sleep discrepancy and depressive symptoms, and prove the efficacy of CBT-I in reducing sleep discrepancies. The additional chronotherapeutic tool showed promising results by enhancing the effect of CBT-I. Future studies should explore the role of sleep discrepancy in common pathophysiology of insomnia and depression, use more sensitive neurophysiological measures, and also involve patients who overestimate their sleep quantity.

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PUBLICATIONS OF THE GRADUATE

8.1. Publications underlying the thesis

a) Publications in English

Janků, K., Šmotek, M., Fárková, E., Kopřivová, J. (2020). Subjective–objective sleep discrepancy in patients with insomnia during and after cognitive behavioral therapy: An actigraphy study. *Journal of Sleep Research*. https://doi.org/10.1111/jsr.13064. ***IF: 3.432***

Janků, K., Šmotek, M., Fárková, E., Kopřivová, J. (2020). Block the light and sleep well: Evening blue light filtration as a part of cognitive behavioural therapy for insomnia. *Chronobiology International*. 37(2), 248-259. ***IF: 2.562***

b) Publications in Czech

Janků, K., Bušková, J., Kopřivová, J. (2019). [Cognitive behavioural therapy for insomnia: changing sleep or its perception?]. *Psychiatrie*, 23(3):115-120.

Veldová, K., Šóš, P., Kopřivová, J. (2015). [Paradoxical insomnia and its causes]. *Psychiatrie*, 19(3):129-135.

8.2. Other publications

a) Publications in English

Anýž, J., Bakštein, E., Dudysová, D., **Veldová, K.**, Lišková, M., Fárková, E., Kopřivová, J., Španiel F. (2019). Politics: no wink of sleep. The effects of global impact events on populations' sleep characteristics. *Social Science & Medicine*. ***IF: 3.007***

b) Publications in Czech

Veldová, K., Lišková, M., Kopřivová, J. (2017). Mezioborový přístup u poruch spánku v lékařské praxi. *Zdravotnictví a medicína*. Online: https://zdravi.euro.cz/clanek/mezioborovy-pristup-u-poruch-spanku-v-lekarske-praxi-485173?seo_name=mlada-fronta-noviny-zdravi-euro-cz

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c) Book chapters

Janečková, D., Weissová, K., Fárková, E., **Veldová, K.**, Lišková, M., Dudysová, D., Šmotek, M., Kopřivová, J., Bendová, Z. [Early bird catches the worm…but what about owls?] In: Horáček, J., Kesner, L., Höschl, C., Španiel F. *Mozek a jeho člověk, mysl a její nemoc*. Praha: Galén, 2016, s.146-152,OSBN:978-80-7492-283-1.