Effect of cognitive behavioural therapy for insomnia on sleep architecture and sleep EEG power spectra in psychophysiological insomnia

KATERINA CERVENA[1,3], YVES DAUVILLIERS[1,2], FABRICE ESPA[1,2], JACQUES TOUCHON[1,2], MILOS MATOUSEK[3], MICHEL BILLIARD[1] and ALAIN BESSET[1,2]

[1]Sleep and Wake Disorder Unit, Gui de Chauliac Hospital, Montpellier, [2]La Colombiere Hospital, Montpellier, France and [3]EEG-Sleep Laboratory, Prague Psychiatric Center, Bohnice, Czech Republic

SUMMARY   There is now an overwhelming preponderance of evidence that cognitive behavioural therapy for insomnia (CBT-I) is effective, as effective as sedative hypnotics during acute treatment (4–8 weeks), and is more effective in long term (following treatment). Although the efficacy of CBT-I in the treatment of chronic insomnia is well known, however there is little objective data on the effects of CBT-I on sleep architecture and sleep EEG power densities. The present study evaluated, first, subjective change in sleep quality and quantity, and secondly the modifications occurring in polysomnography and EEG power densities during sleep after 8 weeks of CBT-I. Nine free drug patients with psychophysiological insomnia, aged 33–62 years (mean age 47 ± 9.7 years), seven female and two male participated in the study. Self-report questionnaires were administered 1 week before and 1 week after CBT-I, a sleep diary was completed each day 1 week before CBT-I, during CBT-I and 1 week after CBT-I. Subjects underwent two consecutive polysomnographic nights before and after CBT-I. Spectral analysis was performed the second night following 16 h of controlled wakefulness. After CBT-I, only scales assessing insomnia were significantly decreased, stages 2, REM sleep and SWS durations were significantly increased. Slow wave activity (SWA) was increased and the SWA decay shortened, beta and sigma activity were reduced. In conclusion CBT-I improves both subjective and objective sleep quality of sleep. CBT-I may enhance sleep pressure and improve homeostatic sleep regulation.

KEYWORDS   beta activity, cognitive behavioural therapy, insomnia questionnaires, psychophysiological insomnia, polysomnography, sigma activity, slow wave activity

INTRODUCTION

Insomnia is among the most frequent health complaints among adults (Hajak, 2000; Morin and Kwentus, 1988). Epidemiological surveys indicate that between 9 and 15% of the population complain of chronic insomnia (Bixler *et al.*, 1979; Ford and Kamerow, 1989; Gallup Organization, 1991, 1995; Mellinger *et al.*, 1985). According to DSM IV [American Psychiatric Association (APA), 1994], psychophysiological insomnia (PPI) is a form of primary insomnia and is found in about 12.5–15% of insomniac patients (Buysse *et al.*, 1994; Coleman *et al.*, 1982). PPI is defined by the International Classification of Sleep Disorders (ICSD, 1997) as a chronic (generally at least 6 months) subjective difficulty in initiating or maintaining sleep and a feeling of non-restorative sleep occurring at least three nights a week. PPI starts in adulthood and is not associated with either pathology or substance abuse.

The aetiology of PPI is complex implicating both psychological and physiological explanatory factors. Psychological, cognitive (dysfunctional beliefs and attitudes about sleep) and

Correspondence: Alain Besset, INSERM E0361, Hôpital la Colombière, P42, BP 34493, 34093 Montpellier cedex 5 France. Tel.: + 33 4 99 614 564; fax: +33 4 99 614 579; e-mail: besset@montp.inserm.fr

behavioural factors (maladaptive sleep habits, excessive time spent in bed, irregular schedule) play pivotal roles in the onset and maintenance of PPI (Espie, 1991; Lichstein and Morin, 2000; Morin et al., 1993; Spielman et al., 1987a). Physiological markers may include an increase in high EEG frequencies, both in the peri-sleep onset period, and during non rapid eye movement (NREM) and rapid eye movement (REM) sleep (Freedman, 1986; Lamarche and Ogilvie, 1997; Merica and Gaillard, 1992; Merica et al., 1998; Nofzinger et al., 1999; Perlis et al., 2001a,b), reduction of slow wave sleep (Gaillard, 1976, 1978) and decreased of power spectra of delta band and theta band in some subjects (Merica et al., 1998; Perlis et al., 2001a). Following total sleep deprivation, percentage three and four sleep stage nearly remains almost unchanged in primary insomniacs whereas it more than doubles in controls (Stepanski et al., 2000). In normal subjects, after partial or total sleep deprivation, a slow wave activity (SWA, EEG spectral density between 0.5 and 4.75 Hz) rebound occurs associated with a spindle density decrease (Dijk et al., 1993), but this phenomenon is less significant or absent in insomniacs (Besset et al., 1998). It may thus be assumed that insomniacs may not have a similar homeostatic response to sleep loss than that seen in normal subjects. This alteration of the homeostatic process leading to insufficient sleep pressure, might be responsible for a chronic inability to initiate and or maintain sleep for a long period.

Primary insomnia may be treated pharmacologically or with cognitive behavioural therapy for insomnia (CBT-I). The primary advantage of medical treatment is that its effects are immediate (Morin et al., 1999). The primary advantage CBT-I is that its effect are substantially more durable. CBT-I has been shown to be as effective as pharmacotherapy (Edinger et al., 2001a; Espie et al., 2001; Morin et al., 1994, 1999; Murtagh and Greenwood, 1995; Smith et al., 2002; Verbeek et al., 1999). Interesting, both therapies produce about the same amount of improvement during acute treatment (Smith et al., 2002). CBT-I refers to a group of treatments that target sleep-related behaviours and maladaptive sleep related cognitions. It involves the use of one or more of the following techniques: sleep restriction therapy, stimulus control, cognitive techniques, relaxation and sleep hygiene education. It is assumed that CBT-I improves sleep by acting upon factors responsible for both sleep maintenance and sleep fragmentation. Low sleep pressure at bedtime may be responsible for a reduced amount of SWA and decreased sigma activity leading to sleep instability and a lower wakefulness threshold. Most studies of the effects of CBT-I in chronic insomnia have shown significant positive effects, and there is little objective data on polysomnography (PSG) sleep architecture and sleep EEG power densities analysis (PSA) after behaviour therapy. In late life insomnia Lichstein et al. (2001) found no change in SWS percentage after sleep compression in which the sleep reduction is not immediate but rather occurs over a prespecified period of time. One study has indicated a significant reduction of beta activity in the presleep period (Jacobs et al., 1993) and when PSA was performed during sleep an increase in delta

EEG power in late-life insomnia was seen after sleep restriction (Hoch et al., 2001). Some previous studies (Besset et al., 1998; Stepanski et al., 2000) have suggested that an alteration of the sleep homeostatic process might be involved in the pathogenesis of insomnia, raising the question as to whether CBT-I might have during the night, an impact on the time course of SWA, the hall mark of the sleep homeostatic process, and on sigma activity which sets the stage for cortical synchronization (SWA) and protects the sleep by inhibiting sensory inputs (Steriade and Amzica, 1998).

In this study we have thus undertaken an evaluation of both subjective change in sleep quality and quantity, and the modifications occurring in PSG and EEG power densities during sleep after 8 weeks of CBT-I.

SUBJECTS AND METHODS

The PPI patients were recruited from the sleep disorders outpatient clinic of the Montpellier University Hospital. *Inclusion criteria for PPI were as follows:*
- Complaint of insufficient and non-restorative sleep.
- Difficulties in sleep initiation (>30 min to fall asleep) and or sleep/maintenance [two or more awakenings per night of >15 min duration and or wake time after sleep onset (WASO) of >30 min] and/or early morning awakening (occurring before 5:00 hours).
- Disturbances in day time functioning.
- Frequency of problem >3 nights per week.
- Problem with duration >6 months.
  Exclusion criteria were as follows:
- A score >13 on the Beck Depression Inventory (BDI, Beck et al., 1961).
- A score ≥ 50 on the State-Trait Anxiety Inventory (STAI, Spielberger, 1983).
- An apnea–hypopnea index (AHI) and/or periodic limb movements (PLM) index >5 and/or restless leg syndrome (RLS) during the first selection PSG night.
- A medical and/or psychiatric disorder.
- Psychotropic drug use over the last month.

The sleep interviews and the medical examination were conducted by physicians board-certified in neurology and sleep medicine (YD, MB), and the psychiatric interview by a psychiatrist (KC). To more precisely characterize insomnia and assess therapy outcome, four additional scales were completed at two times interval (prior to and following CBT-I) and a sleep diary was recorded daily over 1 week. The additional scales were the Insomnia Severity Index (ISI, Morin, 1993), the Dysfunctional Beliefs and Attitudes about Sleep questionnaire (DBAS, Morin, 1993), the Fatigue Severity Scale (FSS, Krupp et al., 1989) and the Epworth Sleepiness Scale (ESS) (Johns, 1991).

Eleven patients complaining of PPI met inclusion criteria and underwent a first (PSG) screening night. Two subjects were excluded because of a pathological AHI (53.7 and 27.7 apnea/hypopnea per hour), none exhibited PLM index >5 and or RLS. Nine subjects aged 33–62 years (mean age

Table 1 Demographic and clinical characteristics of the insomniac patients

Subject	Age (years)	Gender	Marital status	Occupation	Insomnia duration (years)	Type of insomnia	Prior treatment	Stop of treatment before the study
1	62	F	Divorced	Retired	12	SMI	BZD/AD	> 5 Years
2	40	F	Married	Homemaker	2	SOI/SMI/TI	BZD	1 Month
3	60	F	Widowed	Retired	22	SOI/SMI	BZD	1 Month
4	42	F	Married	Employed	4	SMI	BZD	6 Months
5	53	F	Married	Homemaker	30	SMI/TI	BZD/AD	6 Months
6	46	F	Divorced	Employed	14	SMI/TI	BZD	> 5 Years
7	47	M	Married	Employed	15	SMI	BZD/AD	> 5 Years
8	33	F	Married	Homemaker	8	SMI/TI	BZD	2 Years
9	40	M	Married	Employed	11	SOI/SMI	BZD	> 5 Years

SMI, sleep maintenance insomnia; SOI, sleep onset insomnia; TI, terminal insomnia; BZD, benzodiazepine; AT, antidepressant.

47 ± 9.7 years), seven female and two male were enrolled in the study. Three subjects reported sleep maintenance insomnia (SMI), three mixed SMI/terminal insomnia (TI), two mixed sleep onset insomnia (SOI)/SMI, and one mixed SOI/SMI/TI. Demographic and clinical characteristics of the subjects are summarized in Table 1.

Design of the study

As shown in Fig. 1, the study was divided into three periods: baseline period (BLP) and withdrawal period (WP) separated by the CBT-I period. BLP and WP had identical procedure. They were composed of two consecutive PSG nights: N1 and N2 for BLP and N3 and N4 for WP. N1 and N3 were adaptation and screening nights and N2 and N4 PSG nights with PSA. As the SWA level depends on the duration of prior wakefulness (Dann *et al.*, 1984), PSG nights with PSA (N2 and N4) began 16 h after the morning awakening and ended 8 h later. During these 16 daytime hours (D1 and D2), subjects were continuously clinically observed in order to avoid any sleep during the day. CBT-I was conducted over 8 weeks and began the first day following the base line spectral analysis night and ended the day before the adaptation withdrawal night. All subjects attended 8 weekly 60-min individual therapy sessions. In order to evaluate subjective change after therapy, the self-report questionnaires completed before CBT-I: BDI, STAI, ISI, DBAS, FSS and ESS were re-administered on the

last day of CBT-I and no PSG recording was performed during this period.

Polysomnography

The recording montage consisted of a maximum of 13 electrophysiologic derivations for the screening night. The basic montage included two EOG referenced to the single mastoid (LOC/A1 & ROC/A1), two EEG referenced to both mastoids (C3/A2 & C4/A1), a bipolar mentalis EMG and an EKG. In addition, two channels of anterior tibialis EMG, one channel of nasal air flow (nasal pressure canula), one channel of oral air flow (thermocouple), two channels for thoraco and abdominal respiratory movements (piezo-electric) and a channel for SaO2 acquisition were acquired in order to reveal the presence of sleep disorders (sleep apneas, and/or PLMs and/or RLS). EOGs and EEGs were high pass filtered at 0.5 Hz and low pass filtered at 70 Hz, EMGs were high pass filtered at 5 Hz and low pass filtered at 120 Hz, nasal canula was acquired in DC mode and respiratory movements were high pass filtered at 0.15 Hz and low pass filtered at 15 Hz. Low pass filters were 67 tap FIR filters with a 5% transition band designed using a Hamming window.

During PSA nights the montage was reduced to six channels (two EOGs, two EEGs, one EMG and one EKG). All electrophysiologic signals were acquired using Embla A10 (Flaga-Medcare Somnologica 3® software, Flaga hf medical devices, Reykjavik, Iceland).
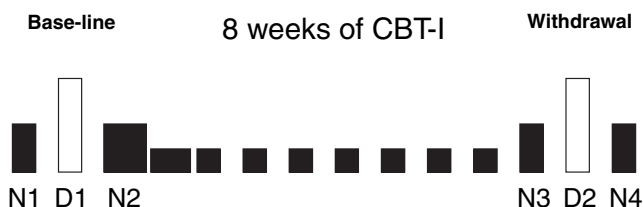
Sleep scoring

The PSG recordings were blindly scored in 30-s epochs according to standardized criteria of Rechtshaffen and Kales (1968) by one of us (KC) specifically trained in PSG scoring.

Sleep onset was defined as the occurrence of three consecutive epochs of stage 1, or 1 epoch of stages 2, 3, 4 or REM. Total sleep time (TST) was the sum of NREM and REM sleep in minutes from 'light off' to 'light on', micro-arousal reactions were computed visually according to the criteria of the American Sleep Disorders Association (ASDA, 1992). They were scored separately by two of us (KC and FE). When

Figure 1. Design of the study: black rectangles represent polygraphic nights. N1 and N3 are adaptation and screening nights, N3 and N4, PSA nights. White rectangle represent 16 daytime hours of controlled wakefulness. Hatched rectangles represents weeks of cognitive behavioural therapy for Insomnia.

differences occurred the final decision was made after discussion. Thus sleep continuity variables were as follow:

- Sleep latency (SL): amount of time elapsed in minutes from 'lights off' to sleep onset.
- Sleep efficiency (SE): ratio of TST to time elapsed in minutes from 'lights on' to 'light off'.
- Wake time after sleep onset (WASO): was the sum of wake time in minutes from sleep onset to the last REM or non REM sleep episode.
- Index of awakenings, defined as the ratio of number of awakenings > 30 s to TST.
- Micro arousal reactions were computed visually according to the criteria of the ASDA (1992). The ratio of number of microarousals to TST defined the micro arousal index (μAI).

Power spectral analysis

The EEGs were digitized on-line at a sampling rate of 200 Hz with 16 bits resolution for the AD conversion (Embla A10, Flaga-Medcare, Somnologica 3® software). Quantitative EEG analyses were performed by PRANA® software (Phitools, Grenoble, France). EEG power spectra were computed for 4-s epochs using the fast fourier transform (FFT) algorithm with a Hamming window overlapping every 2 s. Power spectra were then divided into five frequency bands: SWA (0.5–4.75 Hz), theta (4.75–8 Hz), alpha (8–12 Hz), sigma (12–16 Hz), and beta (16–30 Hz) and averaged over 30-s epochs.

Each epoch was consecutively screened in order to identify epochs with artefacts. Thus epochs which along with waking epochs were excluded from the analysis. In order to enhance ability to resolve average differences as they factor out inter-subjects differences, absolute power values of the five EEG bands were log transformed and relative power (band power over/total power across bands) to give the per cent of brain activity within a given band was calculated. Data were analysed by sleep cycles and TST separately for NREM sleep and REM sleep.

Time course of SWA

The SWA power density in sleep cycles was averaged per cycle. Cycles were defined according to the criteria of Feinberg and Floyd (1979) by the succession of a NREM sleep episode of at least 15-min duration and a REM sleep episode of at least 5-min duration. No minimum REM sleep duration was required for the first and last cycle. For each subject, the SWA cycle value was expressed as the percentage of the total sleep average. SWA values were then plotted against time at cycle midpoint (CMP). CMP was defined as the time elapsed from sleep onset until the middle of the cycle. An exponential decay function with a horizontal asymptote was fitted to the data by a non-linear regression procedure. The fitted function was $SWA_t = SWA_0 \times e^{-t/\tau} + SWA_\infty$, where SWA_0 represents the intercept, the ordinate SWA_0 is 0; t is the time of CMP; τ is the time constant of the exponential function, and SWA_∞ represents the horizontal asymptote if t approaches ∞.

Cognitive behavioural therapy

Therapeutic programme involved, structured, multifaceted intervention with educational, behavioural and cognitive components (Morin, 1993). Eight 60-min individual weekly sessions were given to each subject. At the end of each session patients completed once daily a sleep diary and were also asked to make notes according to a procedural manual for home-based practice.

Session 1: provided general information about the nature, function and regulation of sleep, sleep needs, the effects of ageing and the differentiation of normal and pathological sleep changes. The stimulus control instructions (Bootzin *et al.*, 1991) given to the patients were as follows:

(1) Establish a standard wake-up time.
(2) Avoid sleep incompatible behaviours in the bed/bedroom.
(3) Get out of bed and go to another room when unable to fall asleep within 15–20 min and repeat this step as often as necessary, either when trying to fall asleep or returning to sleep.
(4) Eliminate daytime napping.

Additionally, each subject received an initial time in bed prescription equal to their average sleep times (from baseline sleep diaries) plus 30 min (i.e. normal SL and brief awakenings). The allotted time in bed was never < 5 h per night.

Session 2: comprised information about sleep hygiene principles (the effects of diet, exercise, caffeine, alcohol and environmental factors) and adjusting time in bed (Spielman *et al.*, 1987b) according to the sleep diary data from the previous week. Allowable time in bed was increased by 15–20 min when subject's SE (ratio of TST to time in bed) exceeded 85%, decreased by the same amount when SE was lower than 80%, and kept stable when SE fell between 80 and 85%.

Session 3: entailed reviewing instructions and adjusting time in bed.

Sessions 4 through 7: adjustment of time spent in bed and cognitive therapy aimed at altering dysfunctional beliefs and attitudes about sleep (e.g. beliefs about the immediate and long-term negative consequences of insomnia, unrealistic sleep expectations, beliefs about the need for control over insomnia).

Cognitive therapy sessions followed a three step process:
(1) Identification of patient-specific maladaptive sleep cognitions.
(2) Confrontation and challenging of those cognitions.
(3) Implementation of methods for replacing maladaptive sleep cognitions with more rationale substitutes using cognitive restructuring procedures, e.g. reappraisal, reattribution, decatastrophizing.

Session 8: was devoted to reviewing all therapy instructions and providing information on prevention of insomnia relapse.

Participants received a procedural manual for home-based practice. It should be noted that no relaxation training was performed.

Statistical analysis

Non-parametric ANOVA (Wilcoxon) for paired samples, two-way ANOVA for repeated measures with factors night and cycles and non-linear regression were performed using SAS/STAT software 8.2. (SAS institute, Inc, Cary, NC, USA) Bonferronni correction for multiple comparisons were indicated in term of corrected *P*-value in the tables and Cohen's effect size (Cohen, 1988) was calculated.

RESULTS

Subjective measures

Sleep diaries

As shown in Table 2, subjective sleep onset latency (SOL) and WASO were significantly decreased and TST and SE significantly increased in the last week of CBT after CBT-I as compared with the pretreatment period. The effect sizes were in the very large range of Cohen's standard for WASO and TST and SE and in the large range for SL.

Subjective scales

As shown in Table 3, only scales assessing insomnia (ISI and DBAS) were significantly decreased after CBT-I. Scores on the other scales appraising fatigue, sleepiness, anxiety and depression were not modified. The effect sizes were in the very large range of Cohen's standard.

Polygraphic data

Table 4 summarizes the sleep continuity and sleep architecture variables derived from visual scoring before and after CBT-I. TST and SE were significantly increased and WASO, the index of awakenings decreased in post-treatment night in comparison with pretreatment night. The effect sizes were in the large range of Cohen's standard for TST, WASO, and SE and in the medium range for the awakenings index.

Sleep architecture changes were characterized by increases in stage 2, SWS and REM sleep durations and a decrease in stage

Table 2 Sleep diary data and Wilcoxon test comparisons in insomniac subjects before and after cognitive behavioural therapy for insomnia (CBT-I)

Sleep parameters	Before CBT-I	After CBT-I	Z	P	ES
Total sleep time (min)	281,22 (40.53)	402.66 (37.96)	−2.666	0.008	2.95
Sleep latency (min)	41.63 (40.39)	15.11 (13.51)	−2.521	0.012	−0.84
WASO (min)	125.68 (23.14)	38.01 (15.84)	−2.666	0.008	−4.21
Sleep efficiency (%)	63.14 (10.88)	88.28 (6.40)	−2.666	0.008	2.82

Values in parenthesis represent SD.
WASO, wake time after sleep onset; ES, effect size.

Table 3 Self-report questionnaires and inventories and Wilcoxon test comparisons in insomniac subjects before and after cognitive behavioural therapy for insomnia (CBT-I)

Scales/inventory	Before CBT-I	After CBT-I	Z	P	ES
ISI	16.4 (4.47)	6.3 (3.64)	−3.44	0.0003	2.36
DBAS	4.3 (0.62)	2.3 (0.81)	−3.37	0.0004	2.63
FSS	7.5 (3.36)	4.7 (4.24)	−2.04	0.041*	0.70
ESS	7.9 (6.09)	9.3 (4.69)	−1.10	0.27	0.25
STAI-S	35.2 (7.18)	29.4 (11.69)	−1.5	0.161	0.57
STAI-T	37.1 (9.66)	34.8 (11.34)	−0.985	0.325	0.21
BDI	3.6 (3.9)	2.8 (3.5))	−0.946	0.344	0.21

Values in parenthesis represent SD.
ISI, insomnia severity index scale; DBAS, dysfunctional beliefs and attitude about sleep questionnaire; FSS, fatigue severity scale; ESS, Epworth sleepiness scale; STAI-S, state-trait anxiety inventory (state); STAI-T, state-trait anxiety inventory (trait); BDI, Beck depression inventory; ES, effect size.
*Corrected *P*-value: 0.05/7 = 0.007.

Table 4 Polysomnographic data and Wilcoxon test comparisons in insomniac subjects before and after cognitive behavioural therapy for insomnia (CBT-I)

Sleep parameters	Before CBT-I	After CBT-I	Z	P	ES
Sleep continuity					
Sleep latency (min)	28.17 (13.94)	6.39 (4.08)	−2.67	0.008	−2.02
WASO (min)	113.17 (26.17)	49.00 (39.60)	−2.67	0.008	−1.82
Awakenings index	8.98 (4.90)	6.89 (4.71)	−2.67	0.008	−0.46
μ Arousals index	14.29 (7.78)	13.05 (6.36)	−0.77	0.441	−0.17
Sleep efficiency (%)	67.41 (7.82)	86.52 (8.61)	−2.67	0.008	−2.21
Sleep architecture					
Total sleep time (min)	323.67 (37.32)	415.39 (41.35)	−2.67	0.008	−2.22
Stage 1 (min)	37.50 (15.96)	39.50 (12.68)	−0.77	0.441	−0.13
Stage 1 (%)	11.67 (4.92)	9.59 (3.15)	−1.95	0.051	0.48
Stage 2 (min)	168.39 (33.35)	206.06 (46.60)	−2.67	0.008	−0.89
Stage 2 (%)	52.37 (11.26)	49.36 (8.99)	−2.67	0.008	0.28
Slow wave sleep (min)	62.56 (33.30)	86.50 (23.77)	−2.55	0.01	−0.79
Slow wave sleep (%)	19.09 (9.21)	21.21 (7.13)	−1.24	0.214	−0.24
REM sleep (min)	55.22 (20.33)	83.33 (23.63)	−2.24	0.025*	−1.21
REM sleep (%)	16.87 (5.11)	19.85 (4.97)	−1.60	0.110	−0.56

Values in parenthesis represent SD.
ES, effect size.
*Corrected *P*-value: 0.05/5 = 0.01.

2 percentage after CBT-I in comparison with the period before CBT-I. The effect sizes were in the very large range of Cohen's standard for stage 2 and SWS durations and in the medium range for REM sleep duration and stage 2 percentage.

Time course of SWA

In Fig. 2, values of SWA % were plotted against the cycle midpoints on pooled data for each group (before and after the
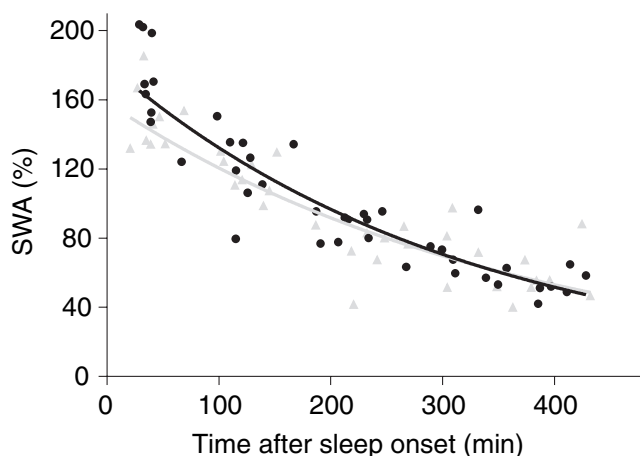
Figure 2. Time course of slow wave activity (SWA) in non-REM and REM sleep per non-REM–REM cycle of insomniacs subjects before cognitive behavioural therapy (CBT) (grey triangles, grey line) and after CBT (black circles, black line). Values of SWA are plotted versus time ad cycle midpoints. 100% represents mean SWA during the night.

CBT-I). In both conditions SWA % declined exponentially from the onset to the end of sleep. An exponential decay function with a horizontal asymptote was fitted to the data, and the regression equation yielded significant correlation coefficients ($P < 0.01$) in both conditions. The estimates of the parameters are summarized in Table 5. Values of r^2 were significant in both conditions but smaller after than before CBT-I. The SWA_0 % value was significantly increased after CBT-I as compared with the period before CBT-I. The τ value (the time constant of the function) was significantly shorter before than after CBT-I. No significant changes were found in SWA_∞ values after CBT-I.

EEG frequency bands

Log transformed absolute values and relative power spectra of EEG bands were analysed separately in NREM sleep and REM sleep. As shown in Table 6, in NREM sleep SWA was significantly increased both in absolute and relative power after CBT-I in comparison with the period before CBT-I. Theta and alpha bands were significantly increased in absolute power but significantly decreased in relative power after CBT-I in comparison with the period before CBT-I. Sigma and beta

Table 5 Summary of the non-linear regression analysis on the time course of mean SWA in NREM and REM sleep over successive sleep cycles and Wilcoxon test comparisons of insomniacs subjects before and after cognitive behavioural therapy for insomnia (CBT-I)

	Before CBT-I	After CBT-I	Z	P
SWA_0	160.17 (18.01)	189.82 (21.34)	−2.67	0.008
τ (min)	163.46 (26.19)	123.15 (27.38)	−2.67	0.008
SWA_∞ (%)	40.78 (06.03)	33.56 (08.38)	−1.60	0.59
r^2	0.86	0.74		

Values in parentheses represent SD.
SWA_0, intercept with the ordinate; t, the time of cycle midpoint; τ, the time constant of the exponential function; SWA_∞, horizontal asymptote if t approaches ∞.

Table 6 The PSA measures of EEG frequency bands in NREM sleep and REM sleep and Wilcoxon test comparisons in insomniac subjects before and after cognitive behavioural therapy for insomnia (CBT-I)

Frequency bands	Before CBT-I	After CBT-I	Z	P	ES
NREM					
SWA[†]	2.82 (0.25)	2.92 (0.21)	−3.75	0.0001	−0.41
SWA[‡]	71.90 (8.42)	76.96 (6.89)	−3.88	0.0001	−0.66
Theta[†]	2.09 (0.19)	2.12 (0.16)	−2.24	0.02*	−0.16
Theta[‡]	13.56 (2.87)	11.34 (2.81)	−3.88	0.0001	0.86
Alpha[†]	1.81 (0.17)	1.85 (0.17)	−2.80	0.005	−0.22
Alpha[‡]	7.58 (2.90)	6.58 (3.19)	−2.69	0.007	0.33
Sigma[†]	1.62 (0.25)	1.62 (0.23)	−0.97	0.33	0.00
Sigma[‡]	5.47 (3.65)	3.88 (2.11)	−3.07	0.002	0.53
Beta[†]	1.06 (0.18)	1.13 (0.26)	−0.90	0.37	−0.30
Beta[‡]	1.50 (0.96)	1.23 (0.72)	−2.26	0.02*	−0.32
REM					
SWA[†]	2.32 (0.26)	2.37 (0.17)	−1.85	0.064	−0.22
SWA[‡]	57.03 (11.28)	58.66 (9.02)	−1.04	0.29	−0.16
Theta[†]	1.89 (0.26)	1.93 (0.18)	−2.09	0.037	−0.17
Theta[‡]	21.36 (4.59)	21.46 (2.47)	−0.36	0.787	−0.03
Alpha[†]	1.59 (0.26)1	1.59 (0.23)	−1.33	0.184	0.00
Alpha[‡]	11.41 (5.98)	10.39 (3.92)	−1.24	0.214	0.20
Sigma[†]	1.21 (0.27)	1.21 (0.23)	−1.35	0.18	0.00
Sigma[‡]	5.47 (3.73)	4.62 (2.51)	−1.57	0.12	0.27
Beta[†]	1.13 (0.27)	1.22 (0.29)	−2.15	0.03*	−0.31
Beta[‡]	4.72 (3.85)	4.84 (2.60)	−0.38	0.72	−0.04

Values in parentheses represent SD.
Power = (μV^2/Hz).
ES, effect size.
*Corrected P-values = 0.05/5 = 0.01.
[†]Log value transformed of absolute power.
[‡]Relative power ([power per bandwidth]/[total power]).

bands were not modified in absolute power but significantly decreased in relative power after CBT-I in comparison with the period before CBT-I. The effect sizes were in the large range for the relative powers of SWA and theta, in the medium range for the absolute power of SWA and the relative powers of alpha and sigma, and in the small range for the absolute powers of theta and alpha of the Cohen's standard. In REM sleep, only beta band was significantly increased in absolute power after CBT-I in comparison with the period before CBT-I. The effect size was in the medium range of Cohen's standard.

In order to appreciate the time course of power spectra bands across sleep cycles a two-way ANOVA for repeated measures with factors night and cycles was performed. SWA was higher in cycles 1 and 2 in comparison with cycles 3 and 4 irrespective of night (Factor night: $F = 10.97$, $P = 0.002$; Factor cycles: $F = 6.46$, $P = 0.002$; interaction night × cycles: $F = 0.99$, $P = 0.410$). No significant differences between sleep cycles were observed in other EEG bands.

DISCUSSION

Subjective data

Our study confirms the efficacy of CBT-I in PPI with improvement of both subjective and objective sleep quality

after 8-weeks of treatment. Subjective improvement was confirmed by the significant post-treatment self-report score on the ISI and DBAS scales (61 and 44% respectively). The ISI scale was found to be a robust measure of treatment outcome as changes over time were found to converge with both objective and subjective measures (PSG, sleep diary) consistent with results obtained by previous studies (Bastien *et al.*, 2001a; Edinger *et al.*, 2001b; Morin *et al.*, 2002). DBAS score changes indicated that dysfunctional beliefs and attitude endorsed by PPI patients are improved with CBT-I. These lower DBAS score were associated with significant improvement of ISI scores and sleep diary data. It is impossible to determine if the changes observed by the patients in sleep continuity may influence their attitude and beliefs about sleep or if cognitive therapy can produce *per se* more adaptative beliefs and attitudes about sleep. Further studies will be needed to determine the precise contribution of each component of the behaviour and cognitive therapy programme in the improvement of the ISI and DBAS scales.

Objective data

Objective improvement of sleep was confirmed by PSG. In accordance with previous studies (Edinger *et al.*, 2001a; Espie *et al.*, 2001; Morin *et al.*, 1999; Verbeek *et al.*, 1999), CBT-I produced the largest effect on sleep fragmentation parameters. SL and WASO were respectively significantly decreased by 57 and 77% and the awakenings index by 23%. This significant sleep fragmentation decrease was responsible for the 28 and 29% increase of SE and TST. With regard to sleep architecture SWS and stage 2 durations were enhanced; but because of the TST increase, SWS percentage was not modified. Nonsignificant increases in SWS and REM sleep percentages may cumulatively have a significant effect in reducing the proportion of stage 2 sleep. The significant increase of REM sleep duration suggests the possibility that CBT-I has an overall normalizing effect on sleep. However the low level of statistical significance require to consider this result carefully.

Power spectra analysis

Beta activity

Several studies (Freedman, 1986; Jacobs *et al.*, 1993; Lamarche and Ogilvie, 1997; Merica *et al.*, 1998; Merica and Gaillard, 1992; Nofzinger *et al.*, 1999; Perlis *et al.*, 2001a,b) have found that high EEG frequencies (beta and gamma) are elevated during sleep onset and during polysomnographic sleep in patients with insomnia suggesting that central nervous system (CNS) 'hyperarousal' may be characteristic of primary insomnia. In the absence of a control group we cannot estimate if beta activity increased in our subjects in comparison with good sleepers. A reduction of beta activity in presleep period has been shown in primary SOI after behaviour therapy (Jacobs *et al.*, 1993). We have not studied beta activity before sleep onset but we observed a reduction of beta activity during

NREM sleep after CBT-I. This result suggests that CBT-I acts upon the CNS hyperarousal during sleep in insomnia. However the low level of statistical significance (which does not reach significance with corrected *P*-value) require to consider this result with caution. Several reasons can be put forward to explain this ambiguous data. (1) we have not analysed gamma frequency and have limited the beta analysis to the beta 1 range (17–30 Hz). This restriction, by decreasing the high frequencies power spectra may have weakened the relationship between cognitive process involved in PPI and beta/gamma activity. (2) It has been shown (Nofzinger *et al.*, 1999; Perlis *et al.*, 1997, 2001a) that increased beta activity is associated with sleep state misperception and it is possible that the degree of misperception remained unchanged after CBT-I, despite objective and subjective improvement in sleep continuity. Further studies are needed to explore this hypothesis. (3) Beta activity may be a trait characteristic not presented by all PPI patients. (4) Beta activity represents 'somatic arousal' (e.g. muscle activity) which is reduced by relaxation therapy which unlike the study of Jacobs *et al.* (1993) has not been used in our study. (5) It is possible that beta activity is not enhanced in PPI and reflects some other activities such as an increase of muscle tone (Bastien and Bonnet, 2001) generally associated with micro-arousals which are not decreased after CBT-I in our study.

Slow wave activity

The SWA was increased both in absolute and relative power indicating that CBT-I is able to reinforce the cortical synchronization. Furthermore the dynamic of SWA throughout the night was also modified: SWA_0 was enhanced and the decay of the exponential function was faster. Very similar changes were observed after 1-night of partial sleep deprivation in SMI patients (Besset *et al.*, 1998). These findings support the hypothesis that sleep pressure, which is supposed to be deficient in PPI patients, could be reinforced by CBT-I and enhance ability to maintain sleep for an extended period.

Sigma activity

Sigma activity is significantly decreased after CBT-I. This seems be due to the increase of SWA after CBT-I. Indeed there is an inverse relationship between SWA and spindles. This relationship is enhanced when sleep pressure is high and diminished when sleep pressure is low (Aeschbach *et al.*, 1994, 1996; Werth *et al.*, 1996). This result reinforces the hypothesis that CBT-I can intensify sleep pressure in insomniacs. However, sigma activity measured by means of spectral analysis based on FFT, cannot distinguish between background activity and organized sleep spindles and we do not know the real part of spindle activity in sigma band. A large part of this band may in fact belong to beta band that could reinforce the hypothesis of a positive action of CBT-I on CNS hyperarousal. It is possible that a hourly index of isolated spindles would constitute a better estimate of spindle activity.

Sleep restriction

It may be concluded from this study, that the observed improvement in sleep architecture is a consequence at least in part of time in bed restriction and stimulus control, which both lead to long-term sleep deprivation in PPI subjects. At the beginning of CBT-I the mean time in bed was 5.5 h per night rising to 7.25 h per night after CBT-I (sleep diary). These data are consistent with polysomnographic findings (TST) and confirm our success in maintaining stable sleep pressure during therapy.

This hypothesis is also consistent with previous studies suggesting that time in bed restriction and stimulus control are the two most efficacious components of CBT-I (Morin *et al.*, 1994). Nevertheless, we are aware of the over-simplified nature of this validation, because in practice the patient's motivation and compliance to therapy are largely because of the other components of CBT-I (educational and cognitive) and it is arguable that use of single time in bed restriction and stimulus control will give rise to a large improvement in macro- and microstructure of sleep in PPI, like the structured multifaceted CBT-I.

Control group

The main limit of our study is the lack of an insomniac control group as it might be hypothesized that sleep improvement is dependant on reasons other than CBT-I. Several observations argue against this hypothesis. First, a positive outcome is observed in all patients, second it is unlikely that such significant modifications in sleep architecture and SWA activity could occur spontaneously after only 8 weeks, and third, if it can be assumed that the care offered to the patients has a therapeutic effect *per se* by decreasing anxiety and reducing stress components then we would expect changes on the anxiety, fatigue and depression scales as well as the scales assessing insomnia.

A larger follow up of PPI patients is required to estimate the length of duration of sleep improvement after therapy, and further investigations and interviews are also needed to determine whether level of SE will increase alone or will need additional sessions of therapy to reach normal levels.

CONCLUSION

The CBT-I improves both subjective and objective sleep quality of sleep. CBT-I may have a favourable effect on CNS hyperarousal by decreasing high EEG frequencies and enhance sleep pressure and improve homeostatic sleep regulation by increasing SWA.

ACKNOWLEDGEMENTS

REFERENCES

Aeschbach, D., Dijk, D. J., Trachsel, L., Brunner, D. P. and Borbély, A. A. Dynamics of slow wave activity and spindle frequency activity in the human sleep EEG: effect of midazolam and zopiclone. *Neuropsychopharmacology*, 1994, 11: 237–244.

Aeschbach, D., Cajochen, C., Landolt, H. P. and Borbély, A. A. Homeostatic sleep regulation in habitual short sleepers and long sleepers. *Am. J. Physiol.*, 1996, 270: R41–R53.

American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV)*, 4th edn. The American Psychiatric Association, Washington DC, 1994.

American Sleep Disorders Association. The Atlas Task Force; EEG arousals: scoring rules and examples. *Sleep*, 1992, 15: 174–184.

Bastien, C. H., Vallières, A. and Morin, C. M. Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep medicine*, 2001a, 2: 297–307.

Bastien, C. H. and Bonnet, M. H. Do increases in beta EEG activity uniquely reflect insomnia? A commentary on "Beta EEG activity and insomnia" (M. L. Perlis et al.). *Sleep Medicine Reviews*, 2001b, 5: 377–379.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J. and Erbaugh, J. An inventory for measuring depression. *Arch. Gen. Psychiatry*, 1961, 4: 561–571.

Besset, A., Villemin, E., Tafti, M. and Billiard, M. Homeostatic process and sleep spindles in patients with sleep-maintenance insomnia: effect of partial (21 h) sleep deprivation. *Electroencephalograph. Clin. Neurophysiol.*, 1998, 107: 122–132.

Bixler, E. O., Kales, A., Soldatos, C. R., Kales, J. D. and Healey, S. Prevalence of sleep disorders in the Los Angeles metropolitan area. *Am. J. Psychiatry*, 1979, 136: 1257–1262.

Bootzin, R. R., Epstein, D. and Wood, J. M. Stimulus control instructions. In: P. Hauri (Ed.) *Case Studies in Insomnia*. Plenum Press, New York, 1991: 19–28.

Buysse, D. J., Reynolds, C. F., Kupfer, D. J., Thorpy, M. J., Bixler, E., Manfredi, R., Kales, A., Vgontzas, A., Stepanski, E., Roth, T., Hauri, P. and Mesiano, D. Clinical diagnoses in 216 Insomnia patients using the International Classification of Sleep Disorders (ICSD), DSM-IV and ICD-10 categories: a report from the APA/NIMH DSM-IV field trial. *Sleep*, 1994, 17: 630–637.

Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd edn. Lawrence Earlbaum Associates, Hillsdale, NJ, 1988.

Coleman, R. M., Roffwarg, H. P., Kennedy, S. J., Guilleminault, C., Cinque, J., Cohn, M. A., Karacan, I., Kupfer, D. J., Lemmi, H., Miles, L. E., Orr, W. C., Phillips, E. R., Roth, T., Sassin, J. F., Schmidt, H. S., Weitzman, E. D. and Dement, W. C. Sleep–wake disorders based on a polysomnographic diagnosis. *JAMA*, 1982, 247: 997–1003.

Dann, S., Beersma, D. G. M. and Borbély, A. A. The timing of human sleep: recovery process gated by a circadian pacemaker. *Am. J. Physiol.*, 1984, 246: R161–R178.

Dijk, D. J., Hayes, B. and Czeisler, C. A. Dynamics of electroencephalographic sleep spindles and slow wave activity in men: effect of sleep deprivation. *Brain res.*, 1993, 626: 190–199.

Edinger, J. D., Wohlgemuth, W. K., Radtke, R. A., Marsh, G. R. and Quillian, R. E. Cognitive Behavioral Therapy for treatment of chronic primary insomnia. A randomized controlled trial. *JAMA*, 2001a, 285: 1856–1864.

Edinger, J. D., Wohlgemuth, W. K., Radtke, R. A., Marsh, G. R. and Quillian, R. E. Does Cognitive-Behavioral Insomnia Therapy alter dysfunctional beliefs about sleep? *Sleep*, 2001b, 24: 591–599.

Espie, C. A. *The Psychological Treatment of Insomnia*. Wiley, Chichester, England, 1991.

Espie, C. A., Inglis, S. J., Tessier, S. and Harvey, L. The clinical effectiveness of cognitive behaviour therapy for chronic insomnia:

implementation and evaluation of a sleep clinic in general medical practice. *Behav. Res. Ther.*, 2001, 39: 45–60.

Feinberg, I. and Floyd, T. C. Systematic trends across the night in human sleep cycles. *Psychophysiology*, 1979, 16: 282–291.

Ford, D. E. and Kamerow, D. B. Epidemiologic study of sleep disturbances and psychiatric disorders. *JAMA*, 1989, 262: 1479–1484.

Freedman, R. EEG power in sleep-onset insomnia. *Electroencephalograph. Clin. Neurophysiol.*, 1986, 63: 408–413.

Gaillard, J. M. Is insomnia a disease of slow wave sleep? *Euro. Neurol.*, 1976, 14: 473–483.

Gaillard, J. M. Chronic primary insomnia: possible physio-pathological involvement of slow wave deficiency. *Sleep*, 1978, 1: 133–147.

Gallup Organization. *Sleep in America*. Gallup Organization, Princenton, NJ, 1991.

Gallup Organization. *Sleep in America*. Gallup Organization, Princenton, NJ, 1995.

Hajak, G. Insomnia in primary care. *Sleep*, 2000, 23(Suppl. 3): S54–S63.

Hoch, C. C., Reynolds, C. F. 3rd, Buysse, D. J., Monk, T. H., Nowell, P., Begley, A. E., Hal, F. and Dew, M. A. Protecting sleep quality in later life: a pilot study of bed restriction and sleep hygiene. *J. Gerontol. B. Psychol. Sci. Soc. Sci.*, 2001, 56: P52–P59.

International Classification of Sleep Disorders revised. *Diagnostic and Coding Manual*. American Sleep Disorder Association, Rochester, 1997.

Jacobs, G. D., Benson, H. and Friedman, R. Home-based central nervous system assessment of a multifactor behavioral intervention for chronic sleep-onset insomnia. *Behavior. Ther.*, 1993, 24: 159–174.

Johns, M. W. A new method for measuring day time sleepiness: the Epworth sleepiness scale. *Sleep*, 1991, 14: 540–545.

Krupp, L. B., La Rocca, N. G., Muir, J. and Steinberg, A. D. The Fatigue Severity Scale: application to patients with multiple sclerosis and systemic lupus erythematosus. *Arch. Neurol.*, 1989, 46: 1121–1123.

Lamarche, C. H. and Ogilvie, R. D. Electrophysiological changes during the sleep onset period of psychophysiological insomniacs, psychiatric insomnias, and normal sleepers. *Sleep*, 1997, 20: 724–733.

Lichstein, K. L. and Morin, C.M. (Eds). *Treatment of late-life insomnia*. Sage Publications, Thousand oaks, CA, 2000.

Lichstein K. L., Riedel B. W., Wilson N. M., Lester K. W. and Aguillard R. N. Relaxation and sleep compression for late life insomnia: a placebo controlled trial. *J. Consult. Clin. Psychol.*, 2001, 69: 227–239.

Mellinger, G. D., Balter, M. B. and Uhlenhuth, E. H. Insomnia and its treatment: prevalence and correlates. *Arch. Gen. Psychiatry*, 1985, 42: 225–232.

Merica, H. and Gaillard, J. M. The EEG of the sleep onset period in insomnia: a discriminant analysis. *Physiol. Behav.*, 1992, 52: 199–204.

Merica, H., Blois, R. and Gaillard, J. M. Spectral characteristics of sleep EEG in chronic insomnia. *Eur. J. Neurosci.*, 1998, 10: 1826–1834.

Morin, C. M. *Insomnia: Psychological Assessment and Management*. Guilford Press, New York, 1993.

Morin, C. M. and Kwentus, J. A. Behavioral and pharmacological treatments for insomnia. *Ann. Behav. Med.*, 1988, 10: 91–100.

Morin, C. M., Stone, J., Trinkle, D., Mercer, J. and Remsberg, S. Dysfunctional beliefs and attitudes about sleep among older adults with and without insomnia complaints. *Psychol. Ageing*, 1993; 8: 463–467.

Morin, C. M., Culbert, J. P. and Schwartz, S. M. Nonpharmacological interventions for insomnia: a meta-analysis of treatment efficacy. *Am. J. Psychiatry*, 1994, 151: 1172–1180.

Morin, C. M., Colecchi, C., Stone, J., Sood, R. and Brink, D. Behavioral and pharmacological therapies for late-life insomnia. A randomized controlled trial. *JAMA*, 1999, 281: 991–999.

Morin, C. M., Blais, F. and Savard, J. Are changes in beliefs and attitudes about sleep related to sleep improvements in the treatment of insomnia? *Behav. Res. Ther.*, 2002, 40: 741–752.

Murtagh, D. R. and Greenwood, K.M. Identifying effective psychological treatments for insomnia: a meta-analysis. *J. Consult. Clin. Psychol.*, 1995, 63: 79–89.

Nofzinger, E. A., Nowell, P. D., Buysse, D. J., Vasco, R. C., Thase, M. E., Frank, E., Kupfer, D. J. and Reynolds, C. F. Towards a neurobiology of sleep disturbance in primary insomnia and depression: a comparison of subjective, visually scored, period amplitude, and power spectral density sleep measures. *Sleep*, 1999, 22(Supp. I): S99.

Perlis, M. L., Giles, D. E., Mendelson, W. B., Bootzin, R. R. and Wyatt, J. K. Subjective-objective discrepancies in psychophysiological insomnia: A neuro cognitive perspective. *J. Sleep res.*, 1997, 6: 179–188.

Perlis, M. L., Smith, M. T., Orff, H., Andrews, P. and Giles, D. E. Beta/gamma activity in patients with insomnia and in good sleeper controls. *Sleep*, 2001a, 24: 110–117.

Perlis, M. L., Merica, H., Smith, M. T. and Giles, D. E. BetaEEG activity and insomnia. *Sleep Med Rev.* 2001b, 5: 363–374.

Rechtshaffen, A. and Kales, A. *A Manual of Standardized Terminology, Techniques, and Scoring Systems for Sleep Stages of Human Subjects*. Brain Information Service/Brain Research Institute, UCLA, Los Angeles, CA, 1968.

Smith M .T., Perlis M .L., Park A., Smith M .S., Pennington J., Giles D. E. and Buysse D. J. Comparative meta-analysis of pharmacotherapy and behavior therapy for persistent insomnia. *Am. J. Psychiat.*, 2002, 159: 5–11.

Spielberger, C. D. *State-Trait Anxiety Inventory for Adults. Sampler Set. Manual, Test, Scoring Key*. Mind Garden, Redwood City, 1983.

Spielman, A. J., Caruso, L. S. and Glovinsky, P. B. A behavioral perspective on insomnia treatment. *Psychiatr Clin North Am.*, 1987a, 10: 541–553.

Spielman, A. J., Saskin, P. and Thorpy, M. J. Treatment of chronic insomnia by restriction of time in bed. *Sleep*, 1987b, 10: 45–56.

Stepanski, E., Zorick, F., Roehrs, T. and Roth, T. Effects of sleep deprivation on daytime sleepiness in primary insomnia. *Sleep*, 2000, 23: 215–219.

Steriade, M. and Amzica, F. Coalescence of sleep rhythms and their chronology in corticothalamic network. *Sleep res. On line*, 1998, 1: 1–10.

Verbeek, I., Schreuder, K. and Declerck, G. Evaluation of short-term nonpharmacological treatment of insomnia in a clinical setting. *J. Psychosom. Res.*, 1999, 47: 369–383.

Werth, E., Dijk, D. J., Achermann, P. and Borbély, A. A. Dynamics of the sleep EEG after an early evening nap: experimental data and stimulations. *Am. J. Neurophysiol.*, 1996, 271: R501–R510.