Chinese Journal of Physiology 48(2): 72-78, 2005

Sleep Dependent Effect of Dark Pulses on Sleep in Albino and Pigmented Rats

Ling-Ling Tsai

Department of Psychology,
National Chung-Cheng University,
Chia-Yi 621, Taiwan, R.O.C.

Abstract

Light-to-dark transitions have been found to enhance paradoxical sleep (PS) in albino rats but not pigmented rats. Furthermore, PS inducing effect of dark pulses in albino rats depends on sleep states. This study examined whether the relationship between PS and preceding non-rapid-eye-movement sleep (NREMS) in pigmented Brown Norway rats was different from that in albino F344 rats and whether such a difference was associated with different responses to dark pulses in the two rat strains. Both rat strains showed a positive relationship between PS and preceding NREMS. However, only the albino F344 rats exhibited the PS inducing effect of dark pulses. Dark pulses did not alter the relationship between PS and preceding NREMS in either rat strain, and, reciprocally, nor did duration of preceding NREMS affect dark pulse-induced PS enhancement. Furthermore, this study verified that dark pulses given during NREMS in albino F344 rats specifically induced the suppression of NREMS concomitant with the enhancement of PS. This study proposed that dark pulses might inhibit NREMS and facilitate PS regulating areas concurrently in albino rats.

Key Words: dark, light, REM sleep, NREM sleep, albino rats, pigmentation

Introduction

Although both are nocturnally active rodents, the albino rat strains (e.g., Sprague-Dawley (9, 10, 13, 14, 21), Lewis (2), Flinders (5), and albino Fischer 344 (F344) (18-20)) and the pigmented strains of rats (e.g., Brown Norway (2, 3), Dark Agouti (4), Long-Evans (4), and pigmented F344 (20)) show different responses of paradoxical sleep (PS) to light-to-dark transitions. Following light-to-dark transitions in short light-dark cycles or during brief exposures of dark pulses, PS increases in albino rats but does not change in pigmented rats. However, a study showed that pigmented Dark Agouti rats had more PS in dark periods than in light periods of a 10-min light and 10-min dark schedule (26).

A recent study found that the PS inducing effect of dark pulses in albino rats depended on sleep states (27). Specific enhancement of PS by dark pulses in albino rats occurs only when dark pulses follow non-rapid-eye-movement sleep (NREMS). That is, the administration of dark pulses to albino rats does not alter PS level when dark pulses follow waking or PS. This work aimed to compare the sleep-state effect of dark pulses on PS in albino F344 and pigmented Brown Norway rats. This study predicted that dark pulses following NREMS would enhance PS in albino F344 rats, but would not alter PS level in Brown Norway rats. This study further compared the relationship between PS and preceding NREMS in the two rat strains to determine whether it was involved in the differential responses to dark pulses. On the other hand, it has been suggested that the effect of dark pulses on PS might be secondary to NREMS suppression (10). If this hypothesis is true, PS enhancement may be specifically associated with NREMS suppression but not with changes in waking. Thus, this study also aimed to verify whether dark pulse-induced NREMS suppression was related to PS enhancement in albino rats.

Corresponding author: Dr. Ling-Ling Tsai, Department of Psychology, National Chung-Cheng University, Chia-Yi 621, Taiwan, R.O.C. Tel.: 886-5-272-0411 ext. 32201; Fax: 886-5-272-0857; E-mail address: psyllt@ccu.edu.tw
Received: October 15, 2004; Revised: November 30, 2004; Accepted: December 7, 2004.

Materials and Methods

Subject and Surgery

Age-matched male albino F344 rats (F344/N) and Brown Norway rats (BN/SsN) were purchased from the National Laboratory of Animal Breeding and Research Center, Taipei, Taiwan, R.O.C. Because of the restriction of availability in local area, pigmented F344 rats were not studied. However, both pigmented F344 rats (20) and Brown Norway rats (2, 3) failed to show PS inducing effect of dark pulses. Before the electrode implantation surgery, they were maintained on a 12-h light and 12-h dark schedule. At the time of surgery, both rat strains were 3-7 months old (independent *t* test between rat strains: $t_7 = 0.1$, $P = 0.92$); F344 rats weighed 230-375 g and Brown Norway rats weighed 260-415 g (independent *t* test between rat strains: $t_7 = 0.7$, $P = 0.51$). The surgical procedure for skull electrode implantation was previously described (7). Briefly, the rats were under pentobarbital (Somnotol) anesthesia (65 mg/kg i.p.). Screw electrodes were implanted aseptically to record ipsilateral cortical EEG (electrodes sites: 1 mm posterior to bregma, 3 mm lateral to the central suture; and 1 mm anterior to lambda, 4 mm lateral to the central suture) and hippocampal theta activity (electrodes sites: 3 mm anterior to bregma, 1 mm lateral to the central suture; and 4 mm posterior to bregma, 1 mm lateral to the central suture). Microwires were sutured to neck muscles to record electromyogram (EMG). All electrodes were connected to a miniature connector and then the connector was mounted with dental cement to a resin base on the skull.

After surgery, each rat was housed in an individual plastic cage ($45\times25\times50$ cm^3) with Lignocel® soft wood bedding on the bottom. The plastic cage was placed in a light-shielded chamber located in a sound-attenuated recording room. The chamber was illuminated by two fluorescent lamps. The lamps were connected to a power switch, under the control of a digital timer. Illuminance level recorded at the cage corners was 180-310 lux during lights-on and less than 1 lux in the dark. Following at least 7 days of recovery from surgery, the electrode connector of each rat was connected by a recording cable to an electrical swivel suspended from a counterbalanced lever. After at least one week of adaptation to the recording cable, EEG, hippocampal theta activity, and EMG recordings were started. The cage temperature was regulated at 24-26°C. Food and water were available *ad libitum*. Food intake, water intake and body weight measurements, and cleaning were performed every other day at random times to maintain the well-being of rats. All the animal facilities and care followed the guidelines provided by the Guide for the Care and Use of Laboratory Animals, National Academy Press, Washington, D.C., 1996 and all procedures and experimental protocols were approved by the Institutional Animal Care and Use Committee.

Recordings

Electrophysiological signals from each rat were passed *via* a long shielded connection cable to amplifiers (BIOPAC Systems, Santa Barbara, CA) in an adjoining room. Amplified hippocampal theta activity was passed to a filter (band pass: 4-7 Hz). Amplified EEG and EMG signals and filtered theta activity were then converted into digital signals with a 64 Hz sampling rate through the MP100 data acquisition unit (BIOPAC Systems) and the DAP2400 e/5 (Microstar Laboratories, Bellevue, WA). Digitized signals from MP100 were displayed on a monitor *via* the AcqKnowledge software (BIOPAC Systems) and stored in a hard disk. DAP2400 e/5 performed automatic on-line data processing. The electrophysiological signals were rectified and integrated over 30-s epoch by the DAP. Every day at a certain time, the previous 24-h collected data was closed and a new file was automatically opened for the next 24-h data collection. Subsequently, the 24-h data were scored for stages as waking, PS, or NREMS substages: low EEG amplitude sleep (LS), medium EEG amplitude sleep (MS), or high EEG amplitude sleep (HS) using the Parametric Animal State Scoring system (8). The LS is characterized as low-amplitude EEG, EMG and theta. The remaining NREMS is subdivided into MS, the portion with EEG amplitude below the modal EEG amplitude of NREMS, and HS, the portion with EEG amplitude above the mode. All the computer-generated sleep scores were compared to the digitized raw signals stored in the hard disk to ensure proper performance of the scoring system.

Experimental Design

After surgery, four albino F344 and five Brown Norway rats were placed on a 23-h light and 1-h dark schedule as a precaution against the possibility of interactions between circadian phase and dark pulse treatment on the sleep and wakefulness states. Under such a lighting regime, circadian rhythms gradually damped out (see Results). The daily one-hour dark period served as a time cue, if any, for the circadian clock and an adaptation period to light-dark transitions. After two to three weeks of adaptation to lighting schedule and to the connection of the recording cable, the rats were subject to the first experimental period. This period was started with one day of habituation to dark pulses, one baseline day and one day of dark pulse treatment. The habituation day served to reduce

the initial sleep-disturbing effect of dark pulses following sleep (27). Following the first period for one week to one month, the second experimental period consisting of one baseline day and one day of dark pulse treatment was started. The sequence of baseline and dark pulse treatment was counterbalanced in both experimental periods. During the day of habituation and dark pulse treatment, an 8-min dark pulse was presented randomly during the normal 23-h light period for 29 to 40 times with inter-dark pulse intervals varying between 24 min and 60 min. The minimum of inter-dark pulse interval was chosen to avoid the incorporation of the period of NREMS and PS suppression immediately following dark-to-light transitions (5, 19, 21, 27) into the 8-min pre-dark pulse data (see below). The dark pulse schedule was determined using a random number generator provided by Microsoft Excel. A hundred numbers between 0 and 1 using the model of uniform distribution were first generated, then sorted, and subsequently converted into the time format. Each time number was added by the time of the end of the daily one-h dark period. The onset time of the first dark pulse was the first transformed time number which fulfilled the criterion of no less than 24 min following the end of the daily one-h dark period. The onset time of the following dark pulses was the transformed time number which fulfilled the criterion of no less than 24-min following the onset time of the previous dark pulse. The onset time of the last dark pulse was at least 16 min before the start of the dark phase period on the next day.

Data Analysis

A 24-h cosine fitting model (1) was applied to mean hourly waking data for each rat to evaluate circadian rhythmicity. Circadian rhythmicity was thought to be present when the statistical *P* value of the cosine curve fit was below 0.05.

The mean 24-h percentage in each sleep and wakefulness state was calculated for each rat on two baseline and two dark pulse treatment days. A two-factor mixed-design analysis of variance (ANOVA) with rat strain (albino F344 *vs*. Brown Norway) by repeated measured variable-experimental day (baseline *vs*. dark pulse treatment) was performed for the 24-h data.

Data blocks containing the 8-min preceding and during the dark pulse period were extracted for each rat. The corresponding data blocks for the same time periods on the baseline day were also extracted (Fig. 1). Data blocks of the baseline over the two experimental periods were pooled for each rat, and so were those of the dark pulse treatment. The percentage of total data blocks in each sleep and wakefulness state was calculated for the 8-min preceding (labeled L1 in the figures and tables) or during the dark pulse period (labeled Dark for the dark pulse treatment data and L2 for the corresponding periods in the baseline, see Fig. 1) for each rat. Based on the sleep and wakefulness states during the last epoch of the preceding lights-on period, the data blocks of each rat were classified into three groups: dark pulse following waking, PS, and NREMS. Subsequently, a three-factor mixed-design ANOVA with rat strain by two repeated measured variables-experimental day and lighting condition (preceding lights-on period *vs*. dark pulse period) followed by Bonferroni-Dunn test was performed for comparing the two lighting conditions on either experimental day and for comparisons on the same lighting condition between experimental days.

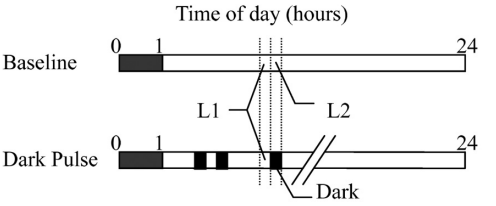

Fig. 1. Schematic diagram of the lighting schedule in the baseline and dark pulse treatment. The solid bars denote the dark period, while the open bars represent the lights-on period. L1, 8-min lights-on period preceding dark pulse; L2, 8-min lights-on period corresponding to the dark pulse period; Dark, 8-min dark pulse period. Three representatives of dark pulses are shown.

As in the previous study (27), the dark pulse following NREMS data blocks were further sorted into two sets, one to four consecutive epochs of NRMES and more than four consecutive epochs of NREMS immediately prior to dark pulses. Three-factor (experimental day, lighting condition, preceding NREMS length) repeated measures ANOVAs followed by Bonferroni-Dunn test was performed for comparing the two lighting conditions on either experimental day and for comparisons on the same lighting condition between experimental days for the two rat strains, separately.

All statistical analyses were performed using SYSTAT® 7.0 for Windows®. An alpha level of 0.05 was used for all statistical tests.

Results

Daily Amounts of Sleep and Wakefulness and Circadian Waking Rhythm

Brown Norway rats displayed a higher daily amount of NREMS ($F_{1,7}$ = 84.6, P < 0.001) and a lower daily amount of waking time than did albino F344 rats (Table 1). However, the dark pulse treatment

Table 1. Percent time (mean ± SD) of waking, NREMS, and PS in 24 hr during the baseline and dark pulse treatment days (Dark Pulse) in albino F344 and Brown Norway rats.

	F344 (n = 4)		Brown Norway (n = 5)	
	Baseline	Dark Pulse	Baseline	Dark Pulse
Waking***	56.41 ± 3.21	55.44 ± 1.62	44.72 ± 2.23	42.77 ± 2.72
NREMS***	35.30 ± 2.81	35.99 ± 1.17	46.42 ± 1.96	47.76 ± 3.00
PS	8.28 ± 0.66	8.56 ± 0.54	8.86 ± 1.01	9.47 ± 0.44

NREM, non-rapid-eye-movement sleep; PS, paradoxical sleep.
***$P < 0.001$, significant difference between the two rat strains

Table 2. Percent time (mean ± SD) of waking, NREMS, and PS in 8 min during the light periods (L1) and the following dark pulse periods (L2/Dark).

	F344 (n = 4)		Brown Norway (n = 5)	
	L1 → L2/Dark		L1 → L2/Dark	
Waking				
Baseline	57.36 ± 4.99	56.37 ± 5.05	41.33 ± 3.48	45.63 ± 2.00
Dark Pulse	54.37 ± 6.34	51.40 ± 3.21	37.92 ± 4.74	43.57 ± 2.76
NREMS				
Baseline	34.30 ± 2.91	35.13 ± 3.59	49.37 ± 4.20	45.27 ± 2.68
Dark Pulse	38.21 ± 4.92	32.68 ± 3.54	51.10 ± 4.63	47.95 ± 3.22
PS				
Baseline	8.34 ± 2.96	8.50 ± 1.56	9.30 ± 3.19	9.10 ± 1.31
Dark Pulse	7.25 ± 2.11	15.92 ± 2.57*#	10.98 ± 1.49	8.38 ± 2.26

Interaction among rat strain, experimental day, and lighting condition was significant on PS ($F_{1,7} = 8.1$, $P = 0.024$).
*$P < 0.05$ *vs.* L1 in dark pulse by Bonferroni-Dunn test.
#$P < 0.05$ *vs.* L2/Dark in baseline by Bonferroni-Dunn test.

did not alter the differences in daily sleep amounts of the rat strain or change the daily sleep amount in either rat strain. Nor did the treatment alter or restore the flattened circadian waking rhythms (see below).

Four albino F344 and three Brown Norway rats gradually lost their circadian waking rhythms on the 23-h light and 1-h dark schedule. The other one albino rat and two Brown Norway rats occasionally showed significant 24-h waking rhythm for one day, and lost rhythmicity on the following days. Because the response trend of these three rats to dark pulses did not differ from that of the other rats of their own rat strain groups, their data were included in all of the statistical analyses shown below.

Effect of Dark Pulse on Sleep and Wakefulness

Table 2 shows that PS increased significantly during 8-min dark pulse periods in albino F344 rats but not in Brown Norway rats. Consistent with the findings of a previous study (27), the PS inducing effect of dark pulse in albino F344 rats depended on the sleep and wakefulness states at the onset of dark pulse. Table 3 shows that waking tended to decrease 5% following NREMS during both the baseline and dark pulse treatment days in albino F344 rats but not Brown Norway rats. NREMS decreased and PS increased following NREMS in both rat strains during the baseline days, whereas NREMS was further suppressed and PS was further enhanced following NREMS in albino F344 rats but not Brown Norway rats during the dark pulse treatment days. The amount of increased PS enhancement following NREMS during dark pulse treatment days (+25.2% *vs.* +9.4% in baseline, i.e., an increase of 15.8%) in albino rats was almost equal to that of increased NREMS suppression (-20% in dark pulse *vs.* -4.3% in baseline, i.e., a decreased of 15.7%). On the other hand, when dark pulses were presented during waking or PS, they failed to alter the sleep and wakefulness states in both albino F344 and Brown Norway rats.

Relationship Between PS and Preceding NREMS

Consistent with the previous findings for

Table 3. Dark pulses following NREMS on percent time (mean ± SD) of waking, NREMS, and PS in 8 min during the light periods (L1) and the following dark pulse periods (L2/Dark).

	F344 (n = 4)		Brown Norway (n = 5)	
	L1 → L2/Dark		L1 → L2/Dark	
Waking				
Baseline	25.77 ± 1.83	20.60 ± 7.53	24.67 ± 3.47	24.96 ± 3.40
Dark Pulse	21.98 ± 2.52	16.82 ± 2.75	24.38 ± 5.26	27.10 ± 5.00
NREMS				
Baseline	67.66 ± 4.83	63.40 ± 6.97	66.83± 1.59	60.73 ± 3.68
Dark Pulse	70.49 ± 4.87	50.45 ± 6.43**$^{\#}$	66.07 ± 5.88	61.90 ± 1.91
PS				
Baseline	6.57 ± 4.40	15.99 ± 3.28*	8.50 ± 2.34	14.31 ± 2.06
Dark Pulse	7.53 ± 2.50	32.73 ± 3.97**$^{\#\#}$	9.55 ± 1.31	11.00 ± 3.61

Interaction among rat strain, experimental day, and lighting condition was significant on PS ($F_{1,7}$ = 27.9, P = 0.001) and NREMS ($F_{1,7}$ = 6.3, P = 0.041).
*P < 0.05 *vs.* L1 in baseline by Bonferroni-Dunns test.
**P < 0.01 *vs.* L1 in dark pulse by Bonferroni-Dunns test.
$^{\#}P$ < 0.05, $^{\#\#}P$ < 0.01 *vs.* L2/Dark in baseline by Bonferroni-Dunn test.

Sprague-Dawley rats (27), longer preceding NREMS was followed by more PS in both albino F344 and Brown Norway rats (Fig. 2). The mean PS percent was increased following more than four consecutive epochs of NREMS, but not following four or less epochs of NREMS, in both rat strains. Dark pulses enhanced mean PS percent in albino rats no matter how consecutive epochs of NREMS were followed by dark pulses.

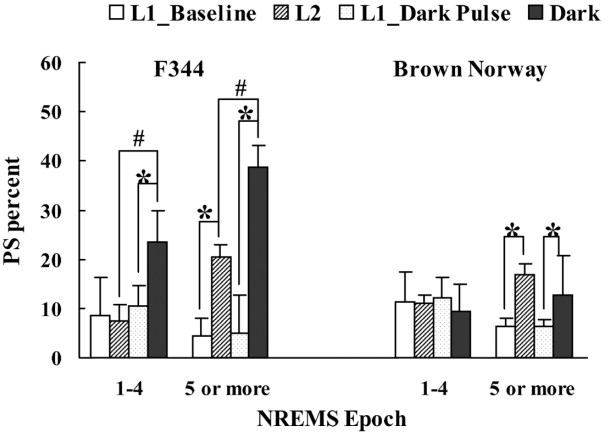

Fig. 2. Interaction between dark pulse and preceding NREMS level on PS percent. PS increased following five or more consecutive epochs of NREMS in both rat strains (albino F344: F1,3 = 103.5, P = 0.002; Brown Norway: F1,4 = 17.7, P = 0.013; *P < 0.05, L1_Baseline vs. L2 or L1_Dark Pulse *vs.* Dark, Bonferroni-Dunn test). The dark pulses further enhanced the mean PS percent in albino F344 rats ($^{\#}P$ < 0.05, L2 *vs.* Dark, Bonferroni-Dunn test). Each value represents mean ± SD. for n = 4 in albino F344 rats and for n = 5 in Brown Norway rats.

Discussion

The main finding of this study was that the relationship between PS and preceding NREMS in albino F344 was similar to Brown Norway rats and was not altered by dark pulses. Furthermore, dark pulses given during NREMS induced NREMS suppression concomitant with PS enhancement.

As demonstrated by the previous study on Sprague-Dawley rats (27), dark pulses presented during NREMS significantly enhanced PS in albino F344 rats, but not in Brown Norway rats. Although both rat strains showed a positive relationship between PS and preceding NREMS (Fig. 2), only the albino F344 rats exhibited the PS inducing effect of dark pulses. Thus, the relationship between PS and the preceding NREMS could not explain the strain difference in PS responses to dark pulses. On the other hand, the PS inducing effect of dark pulse in albino F344 rats was absent when dark pulses were present following waking and PS. That is, rat strain differences in PS responses to dark pulses depended on the sleep and wakefulness states.

This study further showed that PS inducing effects of dark pulses in albino rats were specifically related to the suppression of NREMS during dark pulses. This finding indicates that both NREMS and PS mechanisms are intimately related to dark pulse effect. The relationship between NREMS and PS expression has two contradictory characteristics. One

aspect is the existence of a sequential relationship of NREM to PS expression, i.e., PS does not appear during waking but rather during NREMS. It has been proposed that PS propensity accumulates during NREMS (6). Both this study and the previous study (27) confirmed that PS expression increases with the expression of NREMS. However, the PS inducing and NREMS suppressing effects of dark pulses were independent of NREMS levels prior to dark pulses (Fig. 2). Nor did dark pulses alter the relationship between PS and preceding quantity of NREMS. Thus, it appears that dark pulses enhance PS to express only when there is a certain level of PS propensity.

The other aspect is that a mutually inhibitory interaction occurs between PS propensity and NREMS intensity (11). An increase in either of these two suppresses the expression of the other. The neural mechanism of PS regulation has been proposed as a reciprocal interaction between PS-active (REM-on) and PS-inactive (REM-off) cells located in the brainstem (12, 17). NREM- and waking-regulating cells located in different areas of the brain communicate with REM-on and REM-off cells (16, 25). The interplay of NREM- and waking-regulating cells with REM-on and REM-off cells is presumed to correspond to the relationship among NREMS, waking and PS expression. Since the PS inducing effect of dark pulses depends on the presence of NREMS and is associated with NREMS suppression, this study proposed that both NREMS and PS regulating areas might be involved equally but in opposite directions in the neural mechanism of dark pulse effects.

It has been shown that the eyes were necessary for the PS response to dark to appear in albino rats since bilateral enucleation prevented it (13). Although lesions of the primary optic tract attenuate the PS response to dark, lesions of the accessory optic system, the retinohypothalamic tract-suprachiasmatic nucleus (22), or the visual cortex (19) fail to eliminate it. Removal of the pineal gland (13), which secretes melatonin, a dark-related hormone, or the pituitary gland (26) fails to alter the PS response to the darkness as well. Recently, it has been shown that the pretectum is involved in the PS enhancement of dark pulses (18, 19). Several anatomical differences between albino and pigmented rats have been demonstrated in the retinal projections, e.g., a reduced size of the ipsilateral retinogeniculate pathway (15) but a greater area of retinal termination in the hypothalamic suprachiasmatic nucleus (23) in albinos, and in the afferent and efferent connections of areas receiving retinal projections, e.g., the superior colliculus (24) and the dorsal lateral geniculate nucleus (28). It is likely that there are rat strain differences in the connections between the pretectum and the NREM- and PS-regulating areas whereby results in strain differences in PS responses to dark pulses. However, further studies are still needed to clarify such a proposal.

In summary, this study showed that dark pulses in NREMS enhanced PS in albino F344 rats but not in Brown Norway rats. The positive relationship of PS to preceding NREMS in albino F344 rats remained similar to Brown Norway rats even under the dark pulse treatment. In contrast to PS enhancement, dark pulses in NREMS specifically induced NREMS suppression in albino F344 rats. Thus, it was proposed that dark pulses might inhibit NREMS and facilitate PS regulating areas concurrently in albino rats.

Acknowledgments

Thanks to Yu-Che Tsai and Ching-Sui Hung for their assistance with the experiments.

References

1. Agren, H., Koulu, M., Saavedra, J.M., Potter, W.Z. and Linnoila, M. Circadian covariation of norepinephrine and serotonin in the locus coeruleus and dorsal raphe nucleus in the rat. *Brain Res.* 397: 353-358, 1986.
2. Benca, R.M., Bergmann, B.M., Leung, C., Nummy, D. and Rechtschaffen, A. Rat strain differences in response to dark pulse triggering of paradoxical sleep. *Physiol. Behav*. 49: 83-87, 1991.
3. Benca, R.M., Gilliland, M.A. and Obermeyer, W.H. Effects of lighting conditions on sleep and wakefulness in albino Lewis and pigmented Brown Norway rats. *Sleep* 21: 451-460, 1998.
4. Benca, R.M., Obermeyer, W.H., Bergmann, B.M., Lendvai, N. and Gilliland, M.A. Failure to induce rapid eye movement sleep by dark pulses in pigmented inbred rat strains. *Physiol. Behav*. 54: 1211-1214, 1993.
5. Benca, R.M., Overstreet, D.E., Gilliland, M.A., Russell, A., Bergmann, B.M. and Obermeyer, W.H. Increased basal REM sleep but no difference in dark induction or light suppression of REM sleep in Flinders rats with cholinergic supersensitivity. *Neuropsychopharmacology* 15: 45-51, 1996.
6. Benington, J.H. and Heller, H.C. Does the function of REM sleep concern non-REM sleep or waking. *Prog. Neurobiol*. 44: 433-449, 1994.
7. Bergmann, B.M., Kushida, C.A., Everson, C.A., Gilliland, M.A., Obermeyer, W.H. and Rechtschaffen, A. Sleep deprivation in the rat: II. Methodology. *Sleep* 12: 5-12, 1989.
8. Bergmann, B.M., Winter, J.B., Rosenberg, R.S. and Rechtschaffen, A. NREM sleep with low-voltage EEG in the rat. *Sleep* 10: 1-11, 1987.
9. Borbely, A.A. Sleep and motor activity of the rat during ultra-short light-dark cycles. *Brain Res*. 114: 305-317, 1976.
10. Borbely, A.A., Huston, J.P. and Waser, P.G. Control of sleep states in the rat by short light-dark cycles. *Brain Res.* 95: 89-101, 1975.
11. Endo, T., Schwierin, B., Borbely, A.A. and Tobler, I. Selective and total sleep deprivation: effect on the sleep EEG in the rat. *Psychiatry Res*. 66: 97-110, 1997.
12. Hobson, J.A., McCarley, R.W. and Wyzinski, P.W. Sleep cycle oscillation: reciprocal discharge by two brainstem neuronal groups. *Science* 189: 55-58, 1975.
13. Johnson, J.H., Adler, N.T. and Sawyer, C.H. Effects of various photoperiods on the temporal distribution of paradoxical sleep in rats. *Exp. Neurol*. 27: 162-171, 1970.
14. Lisk, R.D. and Sawyer, C.H. Induction of paradoxical sleep by

lights-off stimulation. *Proc. Soc. Exp. Biol. Med.* 123: 664-667, 1966.
15. Lund R.D. Uncrossed visual pathways of hooded and albino rats. *Science* 149: 1506-1507, 1965.
16. Mallick, B.N., Thankachan, S. and Islam, F. Influence of hypnogenic brain areas on wakefulness- and rapid-eye-movement sleep-related neurons in the brainstem of freely moving cats. *J. Neurosci. Res*. 75: 133-142, 2004.
17. McCarley, R.W. and Hobson, J.A. Neuronal excitability modulation over the sleep cycle: a structure and mathematical model. *Science* 189: 58-61, 1975.
18. Miller, A.M., Miller, R.B., Obermeyer, W.H., Behan, M. and Benca, R.M. The pretectum mediates rapid eye movement sleep regulation by light. *Behav. Neurosci.* 113: 755-765, 1999.
19. Miller, A.M., Obermeyer, W.H., Behan, M. and Benca, R.M. The superior colliculus-pretectum mediates the direct effects of light on sleep. *Proc. Natl. Acad. Sci. USA* 95: 8957-8962, 1998.
20. Obermeyer, W.H. and Benca, R.M. REM sleep in response to light and dark in congenic albino and pigmented F344 rats. *Sleep Res. Online* 2: 83-88, 1999.
21. Rechtschaffen, A., Dates, R., Tobias, M. and Whitehead, W.E. The effect of lights-off stimulation on the distribution of paradoxical sleep in the rat. *Commun. Behav. Biol. Part A* 3: 93-99, 1969.
22. Sisk, C.L. and Stephan, F.K. Central visual pathways and the distribution of sleep in 24-hr and 1-hr light-dark cycles. *Physiol. Behav.* 29: 231-239, 1983.
23. Steininger, T.L., Rye, D.B., Gilliland, M.A., Wainer, B.H. and Benca, R.M. Differences in the retinohypothalamic tract in albino Lewis versus Brown Norway rat strains. *Neuroscience* 54: 11-14, 1993.
24. Taylor, A.M., Jeffery, G. and Lieberman, A.R. Subcortical afferent and efferent connections of the superior colliculus in the rat and comparisons between albino and pigmented strains. *Exp. Brain Res.* 62: 131-142, 1986.
25. Thankachan, S., Islam, F. and Mallick, B.N. Role of wake inducing brain stem area on rapid eye movement sleep regulation in freely moving cats. *Brain Res. Bull.* 55: 43-49, 2001.
26. Tobler, I. and Borbely, A.A. Short light-dark cycles and paradoxical sleep in the rat: Effect of strain difference and hypophysectomy. *Behav. Biol.* 23: 395-398, 1978.
27. Tsai, L.-L. Enhancement of paradoxical sleep by lights-off stimulation depends on sleep states. *Brain Res. Bull.* 57: 639-645, 2002.
28. Turlejski, K., Djavadian, R.L. and Dreher, B. Parabigeminal, pretectal and hypothalamic afferents to rat's dorsal lateral geniculate nucleus. Comparison between albino and pigmented strains. *Neurosci. Lett.* 160: 225-231, 1993.