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Melatonin Rhythm and Sleep Pattern in Antarctica

Moushum Bhattacharyya and Dhurjati Majumdar

Defence Institute of Physiology and Allied Sciences
Lucknow Road, Delhi-110054

ABSTRACT

Melatonin rhythm and sleep pattern of 6 wintering members of the XXIV Indian Scientific Expedition to the Antarctica were investigated during the entire period of journey and stay at Antarctica. The study was carried out at three different geographic locations. Baseline data collection was carried out in November 2004 at Delhi, India, before departing for Antarctica. On board ship, in December 2004 soon after entering the Antarctic Circle and at Maitri (latitude 70° 45’ S, longitude 11° 44’ E) from January 2005 to January 2006. Melatonin was estimated from saliva by ELISA method and sleep was assessed polysomnographically. A consistent delay in the melatonin acrophase was observed during the dark winter months. The mesor of this hormone showed a maximal increase in the midwinter month of June. Polysomnographic recordings of sleep pattern showed a decrease of TST, an increase in sleep latency mainly in the initial summer month, increase in WASO, decreased sleep efficiency, significant reduction in slow wave sleep (stage 3 & 4) and significant increase in stage 1 and 2 and REM sleep during the dark winter months. It was concluded that the changes in circadian rhythm of melatonin secretion in Antarctica might be due the altered photoperiodic conditions. Reduced physical activity and increased sensory information input during winter might have contributed to the decreased deep sleep and increased REM sleep.

INTRODUCTION

Disturbances in sleep, mood, behaviour and biological rhythms are some of the frequent complaints amongst over-wintering expeditioners of the Indian Antarctic Expedition (IAE). Potential disturbances in sleep and circadian rhythmicity in an Antarctic environment which results in consequent decrements in performance efficiency and well being of expedition members are a major concern (Gunderson EKE, 1963; Taylor, 1960; Shurley et al., 1970; Joern et al., 1970; Palinkas et al., 2000). Synchronized body functions with a 24 hr (circadian) periodicity are critical for the maintenance of internal physiological harmony. Environmental and social cues are known to regulate the endogenous circadian rhythmicity of human beings. The neurohormone melatonin released from the pineal gland in close association with the light-dark cycle is known to be involved in regulating sleep and circadian rhythms. Melatonin is considered to provide the best estimate of circadian rhythm phase. Seasonal variation of mood, early morning awakening and sleep disturbances are linked with circadian rhythm function. When desynchronisation between external and internal clock occurs, the temporal orchestra of the human physiological system can quickly get out of tune (Dijk and Cajochen, 1997; Krauchi and Wirz-Justice, 2001; Cajochen et al., 2003; Armstrong, 1989). It has been reported that altered photoperiodic conditions in Antarctica affects the circadian melatonin rhythm (Broadaway and Arendt, 1988; Broadaway et al., 1987; Kennaway and Van Dorp, 1991; Yoneyama et al., 1999), which is known to influence sleep, mood, behavior and other human biological rhythms. It is in this context that the present study was undertaken to find out whether there is any change in the circadian rhythm of melatonin secretion and sleep pattern of tropical Indian expeditioners, who are mostly unkown to the alien Antarctic environment of altered photoperiod and prolonged isolation and extreme cold.

METHODOLOGY

Locations : The observations were made at three locations. Baseline data were collected in Delhi, India in November 2004 before departing for Antarctica. The next set of data were collected on board the ship, in December 2004 soon after entering the Antarctic Circle and the third set of data at Maitri, Antarctica (latitude 70° 45’ S, longitude 11° 44’ E) from January 2005 to January 2006.

Subjects : The study was carried out on 6 wintering members. Their mean (SEM) age, height and weight were 35.7 (2.32) years, 168.3 (2.37) cm and 71.0 (1.88) kg, respectively. Subjects were briefed about the experimental procedures prior to the commencement of the study. None of the subjects suffered from any circadian rhythm or sleep disorder problem on mainland prior to their departure for Antarctica.

Melatonin Estimation : Melatonin was estimated from saliva collected at 8 time points (1100 hr, 1500 hr, 1900 hr, 2300 hr, 0100 hr, 0300 hr, 0700 hr and 1100 hr on the next day) over a of 24 hr period for each subject, at Delhi, onboard ship and at Antarctica on every month from Januray 2005 to January 2006. Samples were pretreated and assayed using Direct Saliva

Melatonin ELISA kits (BÜHLMANN LABORATORIES AG, Switzerland). The absorbance of each sample was read at 450 nm in a microtiter plate reader (VERSAmax, Molecular Devices, USA). Two of the circadian melatonin rhythm parameters, the acrophase (time at which melatonin peaks) and mesor (mean melatonin level during the 24 hr) were estimated using the cosinor method (Nelson, 1979).

Sleep Recordings : Polysomnographic sleep recordings were carried out using a 40 channel polysomnograph (Bravo, Nicolet Biomedical, USA), using the ultrasom software for sleep staging during baseline data collection at Delhi and at Antarctica from January 2005 to December 2005.

Statistical Analysis : Statistical analysis was carried out using one-way ANOVA with repeated measures to see the effect of month on circadian melatonin rhythm and sleep parameters. Student's Newman Keul post-hoc test was applied to see whether there is significant variation between months.

RESULTS

Melatonin **:** The monthly variation in the acrophase of the melatonin rhythm is depicted in **Fig. 1**. Statistical analysis revealed significant ($p < 0.001$) month effect. The acrophase of the melatonin rhythm was delayed by 0.36 hr to occur at 1.98 ± 0.09 hr in the month of December during ship journey soon after entering the Antarctic Circle. The most remarkable shift in the timing of acrophase was observed in the month of January. When compared with baseline acrophase time a maximum delay of 2.82 hr was found in January, resulting it to occur at 4.4 ± 0.03 hr ($p < 0.01$). This delay subsided but continued in the months of February and March. With the start of winter the acrophase delay started increasing in April and continued thereafter till June. It was delayed by 2.26 hr, 2.28 hr and 2.32 hr in April, May and June to occur at 3.88 ± 0.06 hr, 3.9 ± 0.05 hr and 3.94 ± 0.07 hr ($p < 0.01$) of the day, respectively. In the late winter month of July the delay ($p < 0.01$) in the acrophase started to subside with an advance in the month of August. However, there was a significant ($p < 0.01$) delay in the last winter month of September, which continued for the rest of their stay. The monthly variation in the mesor of the melatonin rhythm is shown in **Fig. 2**. Statistical analysis revealed significant ($p < 0.001$) month effect. Mesor level showed a monthly variation of alternate increase and decrease from baseline level to the end of their stay in Antarctica. It increased maximally to 12.6 ± 0.22 pg/ml than the basal level (10.4 ± 0.14 pg/ml) in the dark midwinter month of June.

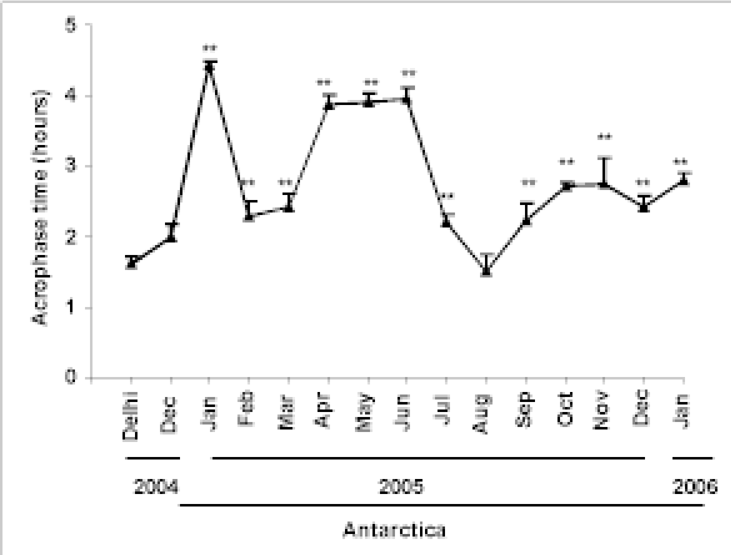

*Fig. 1 : Monthly variation in melatonin rhythm acrophase of six wintering members during their stay at Antarctica. Values are expressed as mean ± SEM. Acrophase timings in different months of stay at Antarctica were compared with baseline acrophase at Delhi. * P < 0.05 and ** P < 0.01*

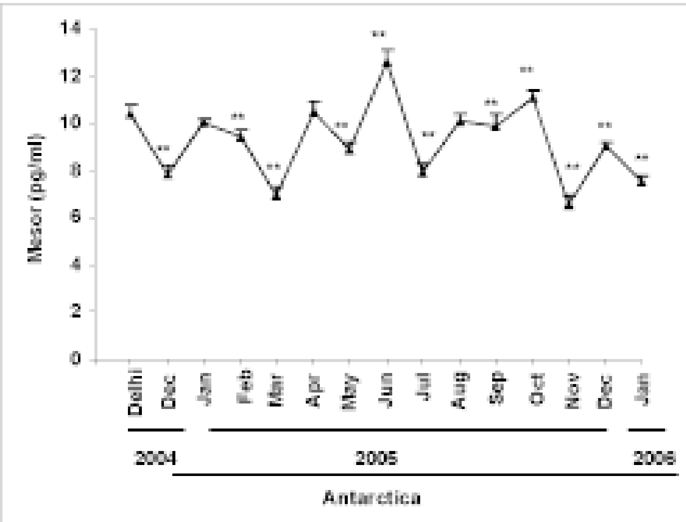

*Fig. 2 : Monthly variation in mesor of melatonin rhythm of six wintering members during their stay at Antarctica. Values are expressed as mean ± SEM. Mesor of melatonin rhythm in different months of stay at Antarctica were compared with baseline mesor at Delhi * P<0.05 and ** P<0.01*

***Sleep* :** Polysomnographic recordings of sleep pattern showed a decrease of TST, an increase in sleep latency mainly in the initial summer month, increase in WASO, decreased sleep efficiency, significant reduction in slow wave sleep (stage 3 & 4) and significant increase in stage 1 and 2 and REM sleep during the dark winter months **(Table 1)**.

Post hoc testing between paired months showed that TST decreased significantly ($p < 0.01$) from baseline values (445.6 min) at Delhi in all the months during stay at Antarctica. The maximum decrease (408.7 min) was observed during midwinter months. Stages 1 and 2 increased significantly ($p < 0.01$) from baseline values at Delhi in all the months during stay at Antarctica, except in the month of November when it decreased from basal value. An average 9% increase than basal value in stage 1 and 2 was observed in midwinter. Stages 3 and 4 showed significant ($p < 0.001$) variation with time (month effect). Post hoc testing revealed that stages 3 and 4 decreased significantly ($p < 0.01$ and 0.05) from baseline values at Delhi in all the months during stay at Antarctica, except in the month of November in which it increased from basal value. This trend of decrease was most pronounced between April and September. There was an average decrease of 13% in stage 3 and 4 in the midwinter than basal value. REM sleep also showed significant ($p < 0.01$) increase with time (month effect) during winter period (April to September) only. It accounted for about 4% increase during midwinter months compared to baseline level. Individual subject responded almost in the same way as that of group average maintaining baseline value in the initial and second summer. However, post hoc testing revealed that REM sleep increased significantly ($p < 0.01$) from the month of April to September compared with baseline level.

DISCUSSION

Results of the present study indicated alterations of melatonin rhythm and disturbances in sleep pattern of normal healthy individuals during their prolonged residency in Antarctica.

A consistent delay was observed in the melatonin acrophase during winter months. The mesor of this hormone showed a monthly variation of alternate increase and decrease from baseline value to the end of their stay with a maximal increase in the midwinter month of June. It is known (Hashimoto et al., 1997; Hashimoto et al., 1996) that human circadian rhythms respond to bright light. During the summer months the light intensity outside the living modules in Antarctica exceeds 1,00,000 lux

Table 1. Sleep characteristics averaged for 6 overwintering members in Delhi and during entire period of stay at Antarctica from January to December 2005. Values are expressed as mean ± SEM.

	Delhi	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
		Antarctica											
Time in bed (mins)	456.3 ± 5.33	452.8 ± 7.09	433.1 ±6.43	435.6 ± 8.62	457.4 ± 4.88	481.0 ± 3.21	467.9 ± 8.95	471.1 ± 6.41	472.5 ± 2.22	470.8 ± 4.02	478.5 ± 3.09	468.2 ± 5.82	450.4 ± 4.90
Sleep latency (mins)	2.4 ± 0.36	7.6 ** ± 1.16	3.6 ± 0.49	2.6 ± 0.40	3.9 ± 0.70	2.5 ± 0.40	2.0 ± 0.22	3.5 ± 0.61	2.4 ± 0.23	2.2 ±0.24	2.2 ± 0.28	2.7 ± 0.37	3.5 ± 0.49
Sleep period total (mins)	453.9 ± 5.34	445.2 ± 7.29	429.5 ± 6.34	433.0 ± 8.73	453.5 ± 4.94	478.5 ± 3.0	465.9 ± 8.95	467.6 ± 6.32	470.1 ± 2.30	468.6 ± 4.09	476.3 ± 3.02	465.5 ± 6.06	446.9 ± 4.88
Wake after sleep onset (mins)	5.9 ± 0.39	22.8** ± 1.21	9.9 ± 0.90	12.9 ± 0.99	20.6** ± 3.54	40.6** ± 1.24	38.8** ± 1.28	35.2** ± 1.40	34.8** ± 0.57	33.5** ± 0.63	30.0** ± 1.68	23.5** ± 1.08	24.8** ± 1.11
Movement time(mins)	2.4 ± 0.18	6.2* ± 0.47	3.7 ± 0.32	5.4 ± 0.40	7.9* ± 1.24	14.1** ± 0.68	18.4** ± 0.60	17.5** ± 0.89	18.9** ± 0.72	16.5** ± 1.34	19.2** ± 1.53	13.8** ± 0.53	12.1** ± 0.48
Total sleepTime (mins)	445.6 ± 5.47	416.2** ± 7.42	415.9** ± 6.39	414.7** ± 8.38	425.0** ± 2.07	423.8** ± 3.32	408.7** ± 7.96	414.9** ± 6.40	416.4** ± 1.89	418.6** ± 2.98	427.1** ± 4.69	428.2** ± 6.98	410.0** ± 4.96

Sleep efficiency	97.7	91.8**	96.8	95.2*	93.1**	88.1**	87.3**	88.0**	88.1**	88.9**	89.2**	91.5**	91.0**
(%)	± 0.14	± 0.24	± 0.20	± 0.19	± 0.92	± 0.26	± 0.15	± 0.42	± 0.16	± 0.29	± 0.61	± 0.42	± 0.35
Mean sleep	100.1	102.7	97.9	101.2	105.5	95.8	94.7	96.4	96.9	93.2	100.4	95.8	94.2
Cycle time (mins)	± 2.88	± 2.46	± 3.03	± 3.05	± 2.43	± 1.49	± 0.99	± 0.86	± 0.77	± 1.05	± 1.37	± 0.97	± 1.03
Stage 1 & 2	57.1	58.6**	58.4**	59.9**	62.0**	63.4**	64.5**	65.5**	66.3**	62.3**	60.2**	56.3**	57.8**
(as % of TST)	± 0.51	± 0.33	± 0.43	± 0.29	± 0.35	± 0.33	± 0.25	± 0.28	± 0.32	± 0.55	± 0.41	± 0.39	± 0.30
Stage 3 & 4	17.9	16.2**	17.1*	14.9**	10.5**	8.6**	7.4**	5.5**	4.8**	10.1**	14.4**	19.0**	17.1**
(as % of TST)	± 0.40	± 0.27	± 0.40	± 0.41	± 0.26	± 0.14	± 0.29	± 0.14	± 0.09	± 0.68	0.62	± 0.38	± 0.27
Stage REM	24.9	25.2	24.5	25.1	27.5*	28.1*	28.7*	29.0*	29.4*	27.6*	25.4	24.7	25.0
(as % of TST)	± 0.54	± 0.28	± 0.46	± 0.41	± 0.26	± 0.28	± 0.61	± 0.29	± 0.16	± 0.22	± 0.87	±0.31	0.42
REM latency	68.3	72.2	73.0	77.9	84.3**	74.6	72.9	71.0	70.8	67.3	78.0	70.4	69.7
(mins)	± 0.93	± 1.03	± 0.93	± 1.03	± 1.56	± 1.03	± 1.60	± 1.08	± 0.85	± 0.79	± 1.31	± 1.44	± 1.22

All comparisons were made against baseline values at Delhi. *p<0.05, **p<0.01 and ***p<0.001.

(Yoneyama et al., 1999), while it is almost at an undetectable level in winter. The delay in acrophase in our subjects was maximum and consistent during the dark winter months of April, May and June. The continuous darkness and the absence of natural dawn signal (Danielnko et al., 2000) during the winter months might be responsible for the delay in acrophase observed in our subjects. It has been also a matter of debate whether the human circadian pacemaker responds to social factors and entrains to social cues (Cugini et al., 1997; Griffiths et al., 1986). The effect of bright light on the circadian pacemaker has been considered as primary, and the social cue has been interpreted as a gate for light information (Duffy et al., 1996). In a place like Antarctica, both these factors act synergistically to cause a disruption in the normal circadian rhythm of many physiological variables (Kennaway and Royles, 1986). Subjects in the present study had knowledge of time and maintained their normal timing for breakfast, lunch and dinner. They also carried out routine outdoor and indoor work according to a strict work schedule. In this study it appears that the altered photoperiod with prolonged absence of sunlight overrides the social cues to act as a strong zeitgeber in influencing the human melatonin rhythm in Antarctica (Kennaway and Dorp, 1991; Yoneyama et al., 1999) contradicting the observation of other investigators (Broadway at al., 1987; Griffiths et al., 1986).

Polysomnographic recordings of sleep pattern showed a decrease of TST, an increase in sleep latency mainly in the initial summer month, increase in WASO, decreased sleep efficiency, significant reduction in slow wave sleep (stage 3 & 4) and significant increase in stage 1 and 2 and REM sleep during the dark winter months. The decrease in slow wave sleep was found to start immediately on arrival at Antarctica, followed by a steep drop from the end of the summer months, which continued throughout the winter. However, it started recovering thereafter towards baseline value in the subsequent second summer months. The reduction of slow wave sleep during the dark winter period in both the Antarctic and Arctic may be attributed to the prolonged absence of sunlight, which might somehow depress hypothalamic function to diminish the pituitary secretion of the human growth hormone, release of which is known to be associated with the onset of stage 4 sleep (Sassin et al., 1969). Subjects of the present study were mostly restricted to indoors during the dark winter months with very little physical exertion. Since it is known that physical activity during daytime increases the duration of slow wave sleep activity, we hypothesize that lack of physical activity during the dark winter months might be somehow responsible for the reduced slow wave sleep found in our subjects (Buguet et al., 1980).

The most interesting finding of the present study is the increase in REM sleep in our subjects during winter which differed with previous reports. REM sleep which was 24.9 ± 0.54 % of TST in Delhi increased to a maximum of 29.4 ± 0.16 % of TST in the month of August in Antarctica. According to the hypothesis of Newman and Evans (1965) and Dewan (1968) the quantity of rapid eye movement sleep varies directly with the information input load since the last period of sleep. Some reports have indicated that intensive cognitive activity or visual stimulation before sleep onset increases REM sleep (De Gennaro et al., 1995; Smith and Lapp, 1991). In Antarctica, the information input load since the last period of sleep was mostly related to events within the station, as communication with the outside world was limited. The various modes of sensory information input during the winter before subjects went to bed were movies, reading books and the daily personal emails which were handed over to the members in printed form by the communication officer twice every day in the morning and at night. It is worthwhile to mention that during winter visual information loading of our subjects increased to manifolds due to continuous watching of movies, playing computer games, reading books, playing cards etc. These activities kept the subjects and other expedition members busy in avoiding the intensity of confinement, isolation and boredom. The observation of increased REM sleep during winter in the present study may be due to a greater magnitude of sensory information received by our subjects prior to sleep onset during the winter months.

In conclusion despite the presence of possible zeitgebers (knowledge of time and social interaction within the group) an internal desynchronisation of the human circadian system is evident in this study. An appropriate combination of artificial light during the dark winter months and a strict social schedule may help in keeping our bodily functions well by alleviating the problems of circadian rhythm disturbance in such extreme and isolated population as in Antarctica. Sleep disturbances may be counteracted by introducing non-pharmacologic therapeutic interventions such as yoga, meditation, and appropriately designed physical exercise during daytime, particularly in the dark winter months when expeditioners mostly remained confined within the station.

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REFERENCES

1. Armstrong SM. Melatonin: the internal zeitgeber of mammals? Pineal Res Rev 1989; 7: 157-202.
2. Broadaway JW, Arendt J, Folkard S. Bright light phase shifts the human melatonin rhythm during the Antarctic winter. *Neurosci Lett,* 1987; **79**: 185-189.
3. Broadaway JW, Arendt J. Seasonal and bright light changes of the phase position of the human melatonin rhythm in Antarctica. Arctic Med Res, 1988; 7: 201-203.
4. Buguet A, Roussel B, Angus R, Sabiston B, Radomski M.Human sleep and adrenal individual reactions to exercise. *Electroencephalogr Clin Neurophysiol,* 1980; **49**: 515-523.
5. Cajochen C, Krauchi K, Wirz-Justice A. Role of melatonin in the regulation of human circadian rhythms and sleep. *J Neuroendocrinol,* 2003; **15**: 432-7.
6. Cugini P, Camillieri G, Allesio L, Cristina G, Petrangeli CM, Capodaglio PF. Ambulatory blood pressure monitoring in clinically healthy subjects adapted to living in Antarctica. *Aviat Space Environ Med,* 1997; **68**: 795-801.
7. Danielko KV, Wirz-Justice A, Krauchi K, Cajochen C, Weber JM, Fairhust S, Terman M. Phase advance after one or three simulated dawns in humans. *Chronobiol Int,* 2000; **17**: 659-668.
8. De Gennaro L, Violani C, Ferrara M, Casagrande M, Bertini M. Increase of REM duration and decrease of REM latency after a prolonged test of visual attention. *Int J Neurosci,* 1995; **82**: 163-168.
9. Dewan DM. The P-hypothesis for dreaming sleep. *Psychophysiology,* 1968; **5**: 203-208.
10. Dijk DJ, Cajochen C. Melatonin and the circadian regulation of sleep initiation, consolidation, structure, and the sleep EEG. *J Biol Rhythms,* 1997; **12**: 627-35.
11. Duffy JF, Kronauer RE, Czeisler CA. Phase-shifting human circadian rhythms: influence of sleep timing, social contact and light exposure. *J Physiol (Lond),* 1996; **495**: 289-97.
12. Griffiths PA, Folkard S, Bojkowski C, English J, Arendt J. Persistent 24-h variations of urinary 6-hydroxy melatonin sulphate and cortisol in Antarctica. *Experentia,* 1986; **42**: 430-32.
13. Gunderson EKE. Emotional symptoms in extremely isolated groups. *Arch Gen Psychiatry,* 1963; **9**: 362-8.

14. Hashimoto S, Koshaka M, Nakamura K, Honma H, Honma S, Honma K. Midday exposure to bright light changes the circadian organization of plasma melatonin rhythm in humans. *Neurosci Let*t, 1997; **221**: 89-92.

15. Hashimoto S, Nakamura S, Honma S, Tokura H, Honma K. Melatonin rhythm is not shifted by lights that suppress nocturnal melatonin in humans under entrainment. *Am J Physiol* (Regulatory Integrative Comp Physiol), 1996; R1073-R1077.

16. Joern AT, Shurley JT, Brooks RE, Guenter CA, Pierce CM. Short term changes in sleep pattern on arrival at the south polar plateau. *Arch Intern Med,* 1970; **125**: 649-54.

17. Kennaway DJ, Royles P. Circadian rhythms of 6-sulphatoxymelatonin, cortisol and electrolyte excretion at the summer and winter solstices in normal men and women. *Acta Endocrinol,* 1986; **113**: 450-456.

18. Kennaway DJ, Van Dorp CF. Free running rhythm of melatonin, cortisol, electrolytes, and sleep in humans in Antarctica. *Am J Physiol* (Regulatory Integrative Comp Physiol), 1991; R1137-R1144.

19. Krauchi K, Wirz-Justice A. Circadian clues to sleep onset mechanisms. *Neuropsychopharmacology,* 2001; **25**: S92-S96.

20. Nelson M, Tong YL, Lee JK, Halberg F. Methods for cosinor-rhythmometry; *Chronobiologia,* 1979; **6**: 305-323.

21. Newman EA, Evans GR. Human dream processes as analogous to computer program clearance. *Nature,* 1965; **206**: 534-536.

22. Palinkas LA, Houseal M, Miller C. Sleep and mood during winter in Antarctica. *Int J Circumpolar Health,* 2000; **59**: 63-73.

23. Sassin JF, Parker DC, Mace JW, Gotlin RW, Johnson LC, Rossman LG. Human growth hormone release - Relation to slow - wave sleep and sleep-waking cycles. *Science,* 1969; **165**: 513-515.

24. Shurley JT, Pierce CM, Natani K, Brooks RE. Sleep and activity patterns at South Pole station. A preliminary report. *Arch Gen Psychiatry,* 1970; **22**: 385-389.

25. Smith C, Lapp L. Increases in number of REMs and REM density in humans following an intensive learning period. Sleep, 1991; 325-330.

26. Taylor IM. Medical experiences at Mc Murdo Sound. In: Horvath S (ed) Cold Injury. Josiah Macy Jr. Foundation, New York, 1960, pp 117-40.

27. Yoneyama S, Hashimoto S, Honma K. Seasonal changes of human circadian rhythm in Antarctica. *Am J Physiol* (Regulatory Integrative Comp Physiol), 1999; R1091-R1097.