Altitude and Seasonality Impact on Sleep in Antarctica

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BACKGROUND: This study investigates the effects of seasonality and altitude on sleep in extreme Antarctic conditions.

METHODS: During summer and winter periods, 24 h of actimetric recordings were obtained at two different research stations, Dumont d'Urville (sea level altitude) and Concordia (corrected altitude 12,467 ft or 3800 m).

RESULTS: During daytime, there were no altitude- or season-related differences in time spent at work, energy expenditure, or number of walking steps. During the nighttime however, total sleep time was longer (m = 427.4; SD = 42.4), sleep efficiency higher (m = 90; SD = 4.8), and wake after sleep onset shorter (m = 42.2; SD = 28.7) at sea level. Additionally, sleep fragmentation episodes and energy expenditure were higher during summer than winter periods.

DISCUSSION: Our results show that dramatic variations in light exposure are not the only main factor affecting sleep quality in Antarctica, as altitude also markedly impacted sleep in these conditions. The effect of altitude-induced hypoxia should be taken into account in future investigations of sleep in extreme environments.

KEYWORDS: hypobaric hypoxia, extreme environments, sleep, polar regions.

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The hostile, confined, and isolated conditions of Antarctica exert a major influence on sleep quality of individuals working in this environment. Indeed, sleep disorders are among the most common problems encountered by Antarctic winter crew,[7] whether in facilities or during expeditions. Chronobiology studies conducted in the Antarctic suggest a desynchronization between sleep and circadian rhythms during the overwintering period which is similar to jet lag, although the exact characterization of the disturbance remains to be elucidated.[10] Moreover, it is suggested that sleep rhythms are predominantly reset by the work schedule, whereas the circadian rhythms are substantially influenced by the photoperiod, eventually promoting a further dissociation between these two regulatory mechanisms in these environments.[15]

Long-term confinement and a prolonged absence or exposure to daylight are expected to influence sleep. One of the few longitudinal studies comparing summer and winter periods reported maximal subjective sleep problems and, more specifically, difficulties in initiating sleep in midwinter (June) as compared to the beginning of winter (March), the end of winter (September), and the summer (December, January).[1] Although restricted movement and subsequently decreased fatigue or homeostatic drive may result in problems with initiating or maintaining sleep in polar regions, it has been also suggested that circadian desynchronization of the sleep-wake rhythm can even be more important.[1]

A parameter which is known to affect sleep, but has not been taken into account so far in Antarctic studies, is the mild to moderate hypoxia due to the altitude of some stations. Hypoxic sleep conditions are characterized by periodic breathing, sleep fragmentation by frequent intermittent awakenings, more light sleep, and a decrease in slow wave and REM sleep.[14] Hypoxic conditions in some Antarctica regions may thus also affect sleep parameters. This phenomenon is

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further amplified by the decreased atmospheric pressure in polar regions, which causes a more important level of hypoxia than for the same altitude at equatorial level. Indeed, the Concordia station is located at an altitude of around 10,761 ft (3280 m),[4] but due to this decreased atmospheric pressure in the polar regions, the level of hypoxia is the equivalent of an altitude of approximately 13,123 ft (4000 m) on the equator.[9] Currently, little is known about how disturbances due to hypoxia and to altered photoperiodicity might interact.

Therefore, this study investigated how sleep is affected in Antarctica both by a hypobaric, hypoxic environment and by constant daylight or night. Actigraphy data were collected at two different Antarctic research stations during summer and winter campaigns, thus generating two conditions with regard to light exposure, with a constant daylight in summer and a constant darkness in winter. Dumont d'Urville (DDU) is located at sea level on the Antarctic coast; Concordia is located at a corrected altitude of 12,467 ft (3800 m), thus generating two strikingly different conditions with regard to hypobaric hypoxia.

METHODS

Subjects

Twenty-six healthy volunteers signed an informed consent prior to inclusion in this study, approved by the IRB of the Vrije Universiteit Brussel (VUB). In the high-altitude Concordia group, eight male crewmembers (median age 36 yr old; SD = 9.8) with a normal mean body mass index (BMI) of 24.2 (SD = 2.2) were tested. In the sea-level DDU group, 18 crewmembers (13 men and 5 women; median age 26.5 yr old; SD = 6.1) with a normal mean BMI of 22.3 (SD = 2.7) were tested. Mean age and BMI were similar between groups (all Fs < 1). All crewmembers were the same during the winter and summer sessions.

Settings

Concordia Research Station is built 10,607 ft (3,233 m) above sea level on the Antarctic Plateau (75°06′ S–123°20′ E). It is located 1,100 km inland from the French station DDU. Due to the latitude, the atmospheric pressure is lower than at the equator and the pressure is, therefore, equivalent to an average altitude of 12,467 ft (3,800 m) (mean atmospheric pressure of 645 hPa), thus creating environmental conditions of chronic hypobaric hypoxia. Mid-November to mid-February is considered the summer period, where daylight is constant. The winter period is from mid-May to mid-August and the sun is completely absent through this period, with 2 mo of complete darkness and a hint of dusk/dawn in the weeks before and after that. The design of the base allows for a virtually completely confined stay in the winter, where all the main components of habitability are brought together in the station.

DDU is a coastal station located at sea level on the Antarctica coast (66°39′ S–140°0′ E). At midwinter there is still a brief period of dawn. The total monthly duration of sunlight in December is 346 h vs. 9 h in August. The DDU base is built as a campus, or a small village, with different buildings according to different functions: dormitories, kitchen and mess, laboratories, etc.

Measurements

One session of 24-h, continuous nondominant armband actigraphy (BodyMedia SenseWear System, Pittsburgh, PA) was recorded during winter (constant darkness) and another one during summer (constant daylight) per subject, in epochs of 1-min bins. Actigraphic recording sessions were planned for 2 to 3 nights. Considering the severe environmental conditions, important data loss due to numerous technical problems occurred; at least only one valid night was recorded across all subjects for all measurements.

Data Analysis

Day-time actigraphic parameters were: 1) time spent at work (TSWd, min), i.e., the time elapsed from the beginning of the recording to bed time; 2) energy expenditure (EEd, J), defined as the total energy expended during TSWd; and 3) the number of walking steps (NSd, absolute number). Nighttime parameters were: 1) time in bed (TIB, min), corresponding to the time elapsed from bed time to the time out of bed; 2) total sleep time (TST, min), defined as the actual time spent asleep; 3) sleep onset latency (SOL, min), defined as the time from bed time until sleep onset; 4) sleep efficiency (SE, %) defined as the ratio between TST and TIB; 5) energy expenditure during the night (EEn, J), defined as the energy expended during TIB; 6) fragmentation (Fr, number), defined as the number of awake periods greater than 1 min after sleep onset; and 7) wake after sleep onset (WASO, min), defined as the total amount of wake time after the first episode of sleep. In order to avoid missing data by subjects who failed to keep a diary and to keep the same way of analysis among all subjects, TIB, TST, and WASO were obtained using a proprietary algorithm provided by SenseWear, Inc. Analyses were performed using IBM SPSS Statistics 21. All outcome variables were tested separately as dependent variables within a mixed ANOVA with Seasonality (two levels: Summer and Winter) as the within-subject factor and Location (two levels: Concordia and DDU) as the between-subject factor.

RESULTS

For the day-time parameters, subjects in Concordia and DDU spent similar amounts of TSWd [**Fig. 1A**; $F(1,24) < 1$], and exhibited similar amounts of EEd [**Fig. 1B**; $F(1,24) = 3.1$; $P = 0.09$; $\eta^2_p = 0.12$] and NSd [**Fig. 1C**; $F(1,24) = 2.03$; $P = 0.17$; $\eta^2_p = 0.08$] in both winter and summer. There were no significant interactions between between location and seasonality.

For the nighttime parameters, TIB [**Fig. 2A**; $F(1,24) < 1$] and SOL [**Fig. 2C**; $F(1,24) < 1$] did not differ between Concordia and DDU, nor between winter and summer. TST in

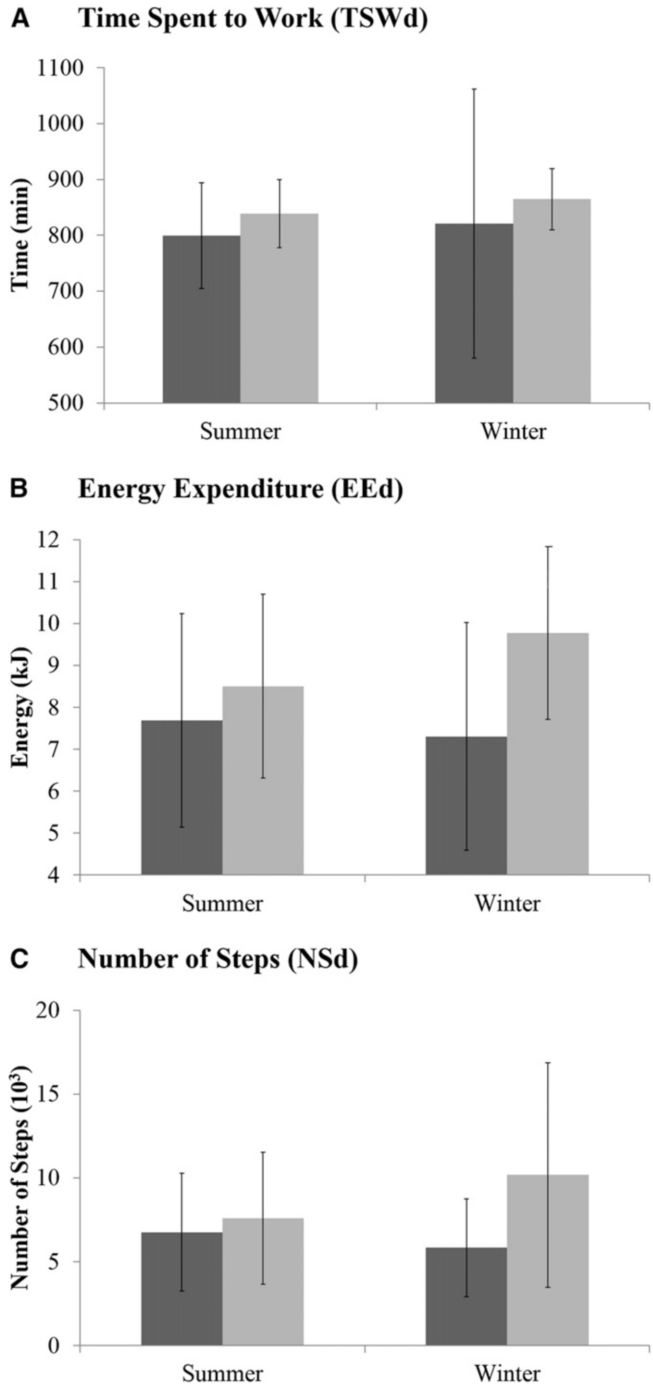

Fig. 1. Day-time parameters recorded at Concordia (dark gray) and DDU (light gray) during summer and winter periods. A) time spent at work (TSWd); B) energy expenditure (EEd); C) number of walking steps (NSd). Error bars represent the SD.

DDU (m = 427.4; SD = 42.4) was longer (**Fig. 2B**) than in Concordia [m = 382.9; SD = 57.5; F(1,24) = 4.9 ; $P = 0.036$; $\eta^2_p = 0.17$] and SE (m = 90; SD = 4.8) was also higher [**Fig. 2D**; $F(1,24) = 4.9$; $P = 0.035$; $\eta^2_p = 0.17$] than in Concordia (m = 83.2; SD = 8). Moreover, statistical analysis showed a significantly longer [**Fig. 2G**; $F(1,24) = 78.8$; $P = 0.01$; $\eta^2_p = 0.27$) WASO for the subjects in Concordia (m = 85.7 ; SD = 44.6) than in DDU (m = 42.2; SD = 28.7). Seasonal differences were observed in the mean number of Fr episodes, which was higher [**Fig. 2F**; $F(1,24) = 11.36$; $P = 0.003$; $\eta^2_p = 0.32$] in summer (m = 10; SD = 7) than in winter (m = 7; SD = 5) and in the mean EEn during the night, which was higher [**Fig. 2E**; $F(1,24) = 4.46$; $P = 0.045$; $\eta^2_p = 0.16$) in summer (m = 2814.5; SD = 559.7) than winter (m = 2501.5; SD = 656). There were no significant interactions between location and seasonality.

DISCUSSION

This study was designed to investigate how hypobaric hypoxia and changes in daylight exposure would affect sleep in Antarctica, and whether these factors would interact. With regard to the effect of seasonality, our results indicate higher fragmentation during sleep and higher nighttime energy expenditure in summer than in winter in both stations. This increased fragmentation could be explained by a circadian desynchronization induced by melatonin secretion delay due to the constant light during summer, as we found in a previous campaign.[8] However, when compared to other studies, this summer/winter difference is surprising, for both Shurley,[12] who showed a higher number of awakenings in winter, and Bhattacharyya et al.,[2] who showed a larger wake after sleep onset during winter, evidenced larger sleep fragmentation in winter than in summer. With no further information on the sleep-wake regulation for these respective data sets, we cannot provide conclusive interpretations of these discrepancies. This further highlights the need for multifactorial sleep investigations in extreme environments, encompassing both the circadian regulation and the homeostatic component.

With regard to the effect of altitude, this study confirms the hypothesis that hypobaric hypoxia at Concordia[3,6] is associated with poor sleep efficiency, with a decrease in total sleep time and an increase in wake after sleep onset, both during summer and winter. We surmise here that the seasonality effect might be due to a circadian disruption, whereas the altitude effect might be due to respiratory events interfering with sleep. Despite the fact that we do not have direct measurements of either circadian markers or respiration to confirm this hypothesis, results from another investigation show the magnitude of the effect of hypoxia on sleep-related breathing.[3] There is still some debate about the influence of periodic breathing on sleep quality, but it is rather accepted that there is a relationship between central apnea and arousals.[5,11] This relationship is believed to decrease sleep continuity due to increased sleep fragmentation. Accordingly, Stadelmann and colleagues[13] found similar sleep EEG changes during periodic breathing and arousals, suggesting that central apnea is associated with microarousals, even if these are not always observable by visual inspection.

Due to the setting of DDU (i.e., built as a campus or a small village), we hypothesized there would be greater physical

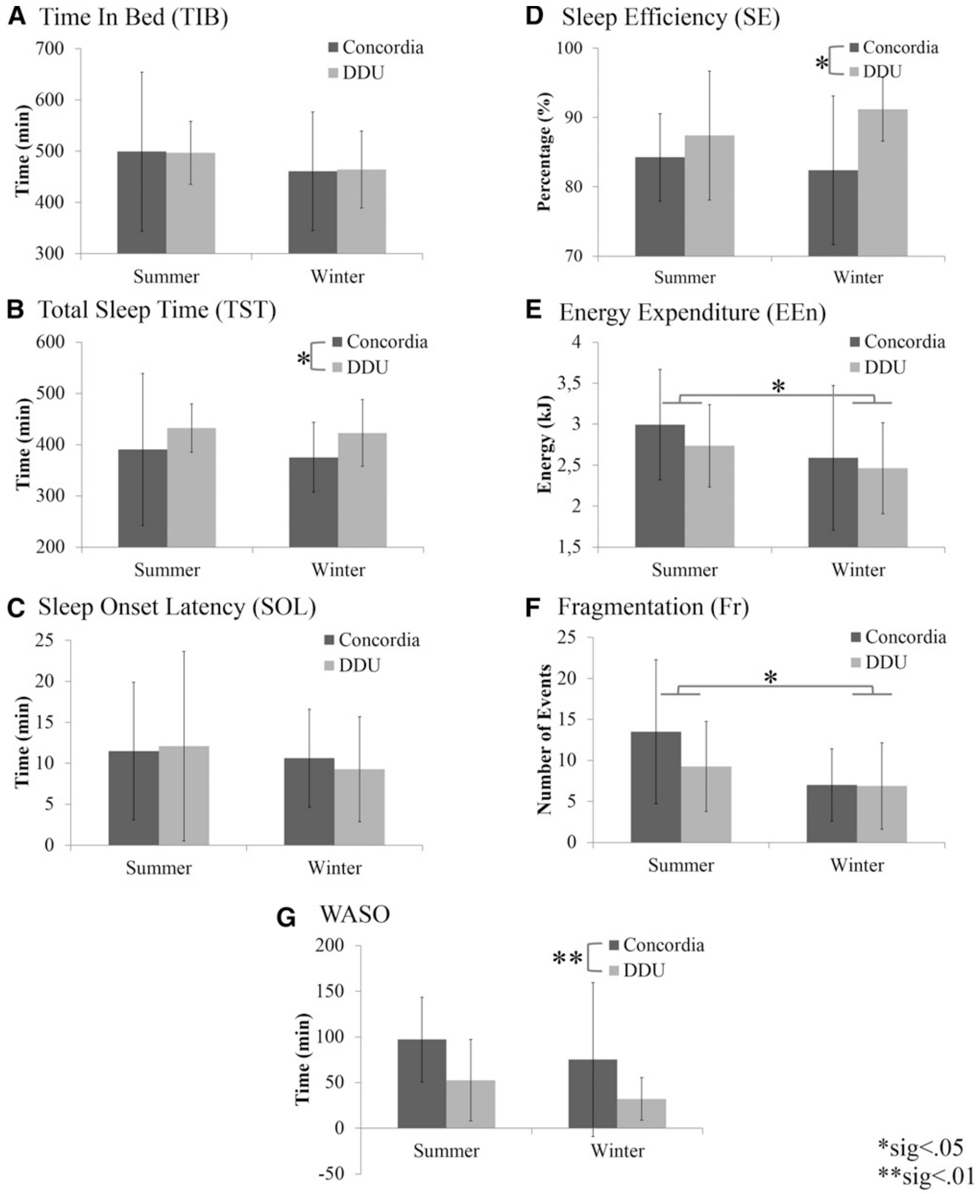

Fig. 2. Night-time parameters at Concordia (dark gray) and DDU (light gray) during summer and winter periods. A) Time in bed (TIB); B) total sleep time (TST); C) sleep onset latency (SOL); D) sleep efficiency (SE); E) energy expenditure (EEn); F) fragmentation (Fr) of sleep; G) wake after sleep onset (WASO). Error bars represent the SD.

activity (energy expenditure awake), leading to a better sleep. However, despite a trend for higher energy expenditure while awake in DDU during winter, activity was similar between stations in terms of time spent awake and walking activity. It suggests that between-group differences in sleep regulation are not attributable to time spent awake, photoperiodicity, or physical activity. Although these conclusions must be moderated by the inherent limitations of the study (e.g., mixed group, different age distribution and small sample size, and evaluation of sleep through actigraphic measurements instead of polysomnography), and considering the difficulties in obtaining scientific data in extreme environments, these findings represent a meaningful addition to the existing literature on sleep in Antarctica.

To sum up, this study shows that dramatic variations in light exposure are not the only main factor affecting sleep quality in Antarctica, as altitude also markedly impacted sleep in these conditions. The effect of hypoxia should, therefore, be taken into account in future investigations of sleep in extreme environments.

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REFERENCES

1. Bhargava R, Mukerji S, Sachdeva U. Psychological impact of the Antarctic winter on Indian expeditioners. Environ Behav. 2000; 32(1):111–127.
2. Bhattacharyya M, Pal MS, Sharma YK, Majumdar D. Changes in human sleep patterns during prolonged stays in Antarctica. Int J Biometeorol. 2008; 52(8):869–879.
3. Tellez HF, Mairesse O, Macdonald-Nethercott E, Neyt X, Meeusen R, Pattyn N. Sleep-related periodic breathing does not acclimatise to chronic hypobaric hypoxia: a 1-year study at high altitude in Antarctica. Am J Respir Crit Care Med. 2014; 190(1):14–16.

4. Fossat E. The Concordia station on the Antarctic plateau: the best site on earth for the 21st century astronomers. J Astrophys Astron. 2005; 26(2-3):349–357.
5. Johnson PL, Edwards N, Burgess KR. Sullivan CE. Sleep architecture changes during a trek from 1400 to 5000 m in the Nepal Himalaya. J Sleep Res. 2010; 19(1, Pt. 2):148–156.
6. Macdonald-Nethercott E, Salam A, Bessone L, Buckle S, Pattyn N. Concordia, Guide de reference. [Concordia, Reference Guide]. Paris (France): European Space Agency; 2012.
7. Palinkas LA, Suedfeld P. Psychological effects of polar expeditions. Lancet. 2008; 371(9607):153–163.
8. Pattyn N, De Valck E, Cortoos A, Pirrera S, Neyt X, et al. Monitoring an Antarctic summer expedition: A constant illumination and physical activity affect mood, cognitive performance and sleep/wake regulation. [Abstract]. Psychophysiology. 2009; 46(Suppl. 1):S103.
9. Radok U, Allison I, Wendler G. Atmospheric surface pressure over the interior of Antarctica. Antarct Sci. 1996; 8(2):209–217.
10. Ross JK, Arendt J, Horne J, Haston W. Night-shift work in Antarctica: sleep characteristics and bright light treatment. Physiol Behav. 1995; 57(6):1169–1174.
11. Salvaggio A, Insalaco G, Marrone O, Romano S, Braghiroli A, et al. Effects of high-altitude periodic breathing on sleep and arterial oxyhaemoglobin saturation. Eur Respir J. 1998; 12(2):408–413.
12. Shurley JT. Physiological research at U.S. stations in Antarctica. In: Gunderson EKE, editor. Human adaptability to Antarctic conditions. Washington (DC): American Geophysical Union; 1974. p. 71–87.
13. Stadelmann K, Latshang TD, Tarokh L, Lo Cascio CM, Tesler N, et al. Sleep respiratory disturbances and arousals at moderate altitude have overlapping electroencephalogram spectral signatures. J Sleep Res. 2014; 23(4):463–468.
14. Weil JV. Sleep at high altitude. High Alt Med Biol. 2004; 5(2):180–189.
15. Yoneyama S, Hashimoto S, Honma K. Seasonal changes of human circadian rhythm in Antarctica. Am J Physiol. 1999; 277(4, Pt. 2):R1091–R1097.