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From the midnight sun to the longest night: sleep in Antarctica

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1. Title Page

Title: From the midnight sun to the longest night: sleep in Antarctica.

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2. Summary

Sleep disturbances are the main health complaints from personnel deployed in Antarctica. The current paper presents a systematic review of research findings on sleep disturbances in Antarctica. The available sources were divided in three categories: results based on questionnaire surveys or sleep logs, studies using actigraphy, and data from polysomnography results. Other areas relevant to the issue were also examined. These included chronobiology, since the changes in photoperiod have been known to affect circadian rhythms; mood disturbances; exercise, sleep and hypoxia; countermeasure investigations in Antarctica; and other locations lacking a normal photoperiod. Based on the combination of our reviewed sources and data outside the field of sleep studies, or from other geographical locations, we defined hypotheses to be confirmed or infirmed, which allowed to summarize a research agenda. Despite the scarcity of sleep research on the Antarctic continent, the present review pinpointed some consistent changes in sleep during the Antarctic winter, the common denominators being a circadian phase delay, poor subjective sleep quality, an increased sleep fragmentation, as well as a decrease in slow wave sleep. Similar changes, albeit less pronounced, were observed during summer. Additional multidisciplinary research is needed to elucidate the mechanisms behind these changes in sleep architecture, and to investigate interventions to improve the sleep quality of the men and women deployed in the Antarctic.

Keywords: polysomnography, actigraphy, polar, insomnia, Antarctica, photoperiod

Abbreviations: AASM: American Academy of Sleep Medicine; aMT6s: 6-sulfatoxymelatonin; GSS: global seasonality score; MEQ: morningness eveningness questionnaire; REM: rapid eye movement; SE: sleep efficiency; SOL: sleep onset latency; S-SAD: subsyndromal seasonal affective disorder; SWS: slow wave sleep; TST: total sleep time; USARP: United States Antarctic research program; WASO: wake after sleep onset.

3. Main Text

Introduction

Antarctica is often described as the most remote place on Earth, the only continent that is still "off the grid", and one of the harshest places to live and work. The most frequently used map projections do not allow to have a clear idea of the size of Antarctica, which is 14 million square km. A projection showing the relative size of the continent is presented in Figure 1. Currently, 28 nations maintain research stations, some of which operate all year round, meaning overwintering personnel is deployed for durations ranging from 12 to 24 months. Figure 2 gives an overview of the different stations on the continent.

Three factors characteristic to long duration sojourns in Antarctica are expected to influence sleep: 1) the lack of a normal occurrence of one daylight and one night-time epoch per period of 24 hours is expected to interact with the circadian regulation of sleep; 2) the confinement and resulting possibly decreased physical activity is expected to interfere with the homeostatic regulation of sleep (i.e. the need for sleep that builds up with the time awake); and 3) the long-duration isolation and confinement is expected to induce psychological adaptation effects which can influence sleep quality and quantity. The occurrence of sleep disturbances in Antarctic regions is indeed a consistent finding in the literature, whether it is investigated through objective or subjective means. As reviewed by Palinkas and Suedfeld (2008) [1], the most common psychological symptoms in polar expeditions include sleep disruptions, impaired cognitive performance, negative affect and interpersonal tension. These findings are far from new, since a review by Guly [2] cites numerous exerts from the earliest papers on psychological symptoms in polar expeditions, or from expeditioners' diaries during the heroic age, and all of those indicate the impact of sleep disturbances on both physical capacity and morale of the crew. Taylor, in 1960 [3], even coined a particular term for the polar insomnia, called "the big eye", which referred to the cluster of symptoms including sleep problems, but also an altered psychological state.

While the presence of sleep problems during either winter (continuous darkness) or summer (continuous light) in Antarctica thus seems mainly undisputed, a precise description of the sleep disorder involving fundamental research on the causal mechanisms is rather limited. Currently, there is a discrepancy in the scientific literature between, on the one hand, the often-reported disturbed sleep in Antarctica, and on the other hand, what looks like the withdrawal from in-depth investigations using the gold standard in sleep measurements, being polysomnography. The most likely reason for this is methodological: polysomnography studies are difficult to implement, require substantial investment in hardware, are unpopular with participants, and labour intensive to analyse. Antarctica, like all extreme environments, offers only small samples of hardly generalizable data, for each expedition or winter over will have its own peculiarities.

The qualification -in terms of sleep architecture- of the observed sleep disturbances is still unclear and the few available reports on polysomnographic investigations of sleep show contradictory results, from heavily disturbed sleep architecture [4] to what authors claimed to be normal sleep [5]. Chronobiology studies during Antarctic sojourns have shown features of circadian desynchronization [6], and psychological investigations have shown mood alterations [7], both being related to sleep disturbances. Moreover, physical activity is allegedly decreased when the weather imposes confinement. However, no set of studies to date allows to draw definitive conclusions about what sleep disturbances in Antarctica mean in terms of sleep architecture. Even if there are reports available pointing to some of their underlying mechanisms (such as a circadian phase delay), an overall consensus on sleep-wake regulation regarding mood and homeostatic sleep drive is still lacking. Hence, the aim of the present paper is to review the available evidence from studies performed in Antarctica investigating sleep, and thus to outline what we know so far about sleep architecture, sleep disturbances and possible countermeasures in this extreme environment. Furthermore, since seasonality is investigated, even in normal conditions, for both sleep and mood disorders; since seasonality has been shown to depend on latitude [8]; and since seasonality is even more marked in Antarctica considering the higher latitudes, the data collected during Antarctic sojourns/expeditions need to be subdivided per the time of year. These different issues can be encompassed by the following questions: i) is there a consistent change in subjective and objective sleep features while staying in Antarctica? ii) are the changes similar or different in summer and winter? and iii) considering the nature of the changes, what are potential hypotheses regarding the causes and subtending mechanisms? Whereas it may seem simplistic to consider only summer and winter regarding the length of daylight exposure, this reductionist choice was made considering the lack of longitudinal data describing evolution of sleep patterns throughout the Antarctic year.

Methodology

The following search engines were used: "Web of Science" for its comprehensiveness (being a commercial subscription tool including both the science citation index and the social science citation index, which warrants for optimal coverage in the psychophysiological field); and "Medline" for its inclusion of non-indexed journals (hence with no defined impact factors), which is sometimes the case in niche publications about extreme environments.

Search terms included all the possible combinations of "sleep", "Antarctic*" and "polar". The search was performed for all publications until January 31st 2017. Considering the paucity of publications, the only inclusion criterion was to measure sleep. Relevant retrieved hits from indexed journals were additionally scanned using the "citation map" tool of "Web of Science", allowing for backward and forward citation map searches. The papers which were not available through "Web of Science" were manually scanned based on their reference lists. This procedure was followed for each selected paper. Since for all extreme environments, the initial research was performed as a way of optimizing the operational support to expeditions, the medical directors of national Antarctic programs with a significant history of winter-over stations were contacted personally to enquire about relevant unpublished data in national reports. Responses were obtained from representatives from the UK, USA, New Zealand, Australia, Japan, Germany and France.

Three types of data sources are available: studies using subjective measures of sleep quantity and quality (i.e. sleep diaries or questionnaires); studies using actigraphy; and studies using polysomnography, with some reports combining different methods (e.g. questionnaires and actigraphy). Furthermore, some of the available investigations are not solely descriptive, but research the effect of an intervention (mostly light exposure, but also exercise and nutrition), in which case we used the baseline or control data. The effect of the investigated countermeasures is discussed separately.

Considering the paucity of available sleep studies in Antarctica, no additional inclusion criteria were defined for the investigations using either actigraphy or polysomnography. For questionnaire studies, we have included the articles investigating sleep, with instruments varying from sleep log or diaries to questionnaires, as long as sleep was specifically mentioned and measured, and as long as an explanatory dimension was found in the study. Hence, we did not include solely descriptive studies (i.e. reporting rest/activity rhythms), but those which aimed at investigating the link of sleep disruptions with other variables (be it circadian, behavioural or geographical). We did not include broader longitudinal studies of mood and psychological presentations which did not include sleep in the dimensions evaluated. This identified nine papers, two of which investigated countermeasures: light exposure to accelerate recovery from shift-work [9]; and ornithine intake [10].

As for actigraphy, seven papers were identified. Studies using a combination of subjective measures (either sleep diary or questionnaire) and actigraphy are classed in this category. Four of these papers investigated light exposure as an intervention [11-14].

Seven articles were identified reporting sleep studies having used polysomnography. The most significant data set was found in a monograph [15] made available by the US representative to the joint expert group on human biology and medicine from the scientific committee on Antarctic research from their national archive. One paper [16] was identified by backward searches, however, the original article is a letter to the editor, containing no data to support the claim made by its author, namely that Russians investigations did not corroborate the disturbances evidenced by the American investigations by Shurley [15]. As this source is written as a letter, not including any data and reflecting only the author's opinion and interpretation with no means to verify it, we chose not to discuss it here, for it cannot be critically appraised.

A summary of the relevant methodological features of the discussed publications is presented in Tables I, II and III. As described in those overview tables, the range of environmental differences between various stations warrants for additional methodological distinctions.

A first necessary sub-categorisation is between stations at sea level and stations at altitude. Indeed, when reviewing the available evidence, one can draw a line between the studies at South Pole and Concordia, which are both at altitude (2800 m for South Pole, 3233 m for Concordia) on the one hand, and the investigations at sea level on the other hand (Halley, Dumont d'Urville, Maitri, Neumayer, Syowa, Scott, Artigas). However, this leaves a location like Princess Elizabeth (1382 m) somewhat in the middle. As described by Shurley, the location of the South Pole station, at 90° S and an elevation of 2800 m above sea level creates a quite unique environment, with a mean pressure altitude of approximately 3350 m -atmospheric pressure being lower at the poles-, qualifying it as a high-altitude observatory [15]. The same thing holds true for Concordia. Subjects in those stations are thus additionally exposed to chronic hypobaric hypoxia.

A second distinction needs to be made based on the duration of the continuous daylight versus night time. Indeed, at South Pole (90°S), deployed personnel are experiencing one continuous day of five and a half months during summer followed by one continuous night of five and a half months during winter, with a two-week period of twilight occurring around each. This additional difference is related to the duration of exposure to a lack of daylight, which is one of the factors most likely to influence sleep. Indeed, the different latitudes of the different stations indicate the duration of exposure to the lack of daylight to be different as well, as summarized in the overview tables. However, when looking at results for either summer and winter, the identified articles all included measures in the periods of constant or near-to-constant daylight/darkness, which we thus considered appropriate to compare when looking at data recorded at the height of summer (December-January) or winter respectively (June-July).

Since the lack of physical activity has been suggested to have an influence on sleep quality during Antarctic overwintering, the degree of confinement imposed by the type of station should also be considered. In stations with prolonged periods of darkness, temperatures below -50°C in winter, and a monotonous landscape with very little to no wildlife (such as South Pole, Concordia, Dome Fuji or Halley), there is no outdoors recreation possible outside of the summer season. This affects not only the degree of physical activity, but also the mood of participants. For this reason, this variable is also described.

Finally, it needs to be emphasized that we can only discuss the variables that were reported by the authors, and the degree of detail varies with each publication.

i) Is there a consistent change in sleep architecture in Antarctica?

Subjective measures

Four studies investigating sleep and circadian rhythms showed disturbed sleep-wake rhythms. Ross et al. [9] evidenced a higher SOL and lower TST in their baseline winter measures. Kennaway & Van Dorp [17] showed a sleep-wake and melatonin secretion pattern that evolved to free-running in the period of complete darkness, with a decreased sleep duration in only one of their subjects. Yoneyama et al. [18] showed a dissociation between seasonal changes in melatonin secretion, and stable sleep rhythms. Despite the description of sleep not being the primary focus of their paper, when looking at the reported data (Figure 2), it clearly shows that monthly averages of sleep duration show the greatest interindividual variability in the period of total darkness. Usui et al. [19] showed a decreased sleep quantity in winter, as well as seasonal phase shifts. Overall, these circadian investigations suggest a pattern of phase delay in winter, which is associated with a decrease in sleep quantity, although the precise description hereof (fragmentation vs increased SOL; or both) is not clear so far. Palinkas et al. [20] reported on a large-scale investigation targeting seasonal variations in sleep characteristics and their association with mood during overwintering across the 3 year- round stations of the USARP (United States Antarctic research program). Per their results, seasonality had little to no impact on sleep, but there were significant differences between stations, which they ascribe to latitude, and thus exposure to a loss of alternating daylight/night-time in a 24 hours' epoch (the higher the latitude, the longer the loss of this normal rhythm of daylight exposure, the more adverse the consequences on sleep). However, South Pole, McMurdo and Palmer (the three USARP stations) are very different in crew sizes and possibilities of outside activities, so one cannot rule out further influencing variables. Furthermore, these authors evidenced a reciprocal relationship between sleep characteristics and mood: changes in mood were preceded by changes in sleep, whereas mood changes were also shown to affect sleep quality. Lastly, considering the altitude differences between stations, this may also be a significant confound. Even though Weymouth & Steel [21] only investigated four nights upon arrival in the summer season, their results show a decrease in self-reported sleep quality, with no decrease in sleep quantity. Tassino et al. [22] performed a similar investigation: a short stay of a cohort during summer. Interestingly, these authors point out the fact that the stay on an Antarctic station acted as a synchronizer on most variables, probably because of the fixed schedule the participants (students to a summer school) were submitted to. Sleep duration diminished significantly during deployment but the subjective assessment of sleep quality was not affected. Finally, Horiuchi et al. [10] show a decrease in the restorative quality of sleep ("feeling refreshed") and in sleep duration compared to pre-deployment measures.

Actigraphy

Gander et al. [23] report a pattern of sleep compatible with circadian desynchronization upon arrival in Antarctica, which had adverse consequences on subjective sleep ratings as well. Despite the sleep-wake rhythm looking synchronized, due to the constraints of the working schedule, nightly body temperature, heart rate and activity were higher in Antarctica. Two of their three subjects reported significant difficulty falling asleep, difficulty waking up in the morning, feeling less rested and with a poorer overall sleep quality. Francis et al. [11], Mottram et al. [12] and Corbett et al. [13] investigated the exposure to light in the same station, Halley. Francis et al. [11] and Mottram et al. [12] report results of a very similar protocol, investigating the difference between bright white light exposure and blue enriched light exposure, whereas Corbett et al. [13] reports results of a one hour bright white light exposure in the morning. In their baseline recordings, Francis et al. [11] evidenced an overall poor sleep efficiency, due more to a high sleep fragmentation than to an increased sleep onset latency. Furthermore, on days when the participants' schedule was not dictated by work constraints, there was a clear delay in sleep onset and sleep offset timing. Mottram et al. [12] report a continuation of the previous study with a difference in the intensity of the blue-enriched light (17000 K vs the previously used 10000 K), and their baseline data show better sleep efficiency. It needs to be underscored that both studies perform their baseline measurements in spring and autumn, thus the data we discuss here are recorded at the only periods of the year where there is a sunrise in the morning and a sunset in the evening -albeit with rapidly changing durations-. Yet sleep is still disturbed.

Corbett et al. [13] report even better sleep efficiency in their baseline data, but similar subjective sleep assessment, and a higher alertness rating in the evening than in the morning. It is interesting to note the difference in control data from Corbett et al., which were recorded after sundown, hence in the period of constant darkness; and those from Francis et al. and Mottram et al., which were recorded during spring and autumn: one would expect better sleep in the periods of the year where an alternating exposure to daylight and night-time darkness is present. However, these data show quite the opposite. These are of course different campaigns, with different participants, however, they all occur at the same station, hence giving a certain level of standardization (similar environment, crew composition, recruitment criteria from the operator, culture etc.). And the point we wish to make here is that the data which are recorded at the time of year where sleep is supposedly the most affected by the lack of daylight exposure show the least disturbance. All report using the same hardware and method to compute sleep parameters, the only difference being recordings in 2 minutes' epochs for Francis et al. and recording in 30 s epochs for Mottram et al. and Corbett et al.

Najjar et al. [14] also investigated exposure to blue enriched white light during a winter at Concordia station. In their baseline condition, they evidenced a significant delay in bedtime and time of lights off, as well as poor sleep efficiency. Collet et al. [24] report a comparison of altitude and seasonality effects on sleep in two different stations: Dumont d'Urville and Concordia. Sleep disturbances are more pronounced at Concordia, and there are no significant differences in daytime physical activity between summer and winter in neither station. However, the evidence base is quite small, with a single recording for each season. The authors stress the effect of chronic hypobaric hypoxia as being more important than the disturbed photoperiod. Steinach et al. [25] are the first to investigate the influence of gender on sleep patterns in an impressive data set, pooling data from seven consecutive winters at Neumayer. Furthermore, they are also the first to confirm the decrease in physical activity over winter, but only for their male subjects. Sleep parameters revealed lower sleep efficiency, a delayed sleep onset latency and a delayed awakening, where this decrease in sleep quality was significantly more pronounced in women. Chen et al. [26] report a longitudinal investigation of sleep, mood and circadian rhythms before and during an overwintering. Their results confirm previous findings, since they evidence a phase delay both in 6-sulfatoxymelatonin (aMT6s) excretion and in sleep timing (sleep onset, sleep offset and mid-sleep time). However, no other sleep disturbances are reported. Furthermore, their questionnaire data reveal two noteworthy facts: a decrease in the average MEQ (“morningness eveningness” questionnaire) score during winter, coupled to an increase of the GSS (global seasonality score). This indicates that what has previously been assessed as a rather stable trait-like dimension varies when exposed to an Antarctic winter. In addition, 2 of the 15 respondents met the criteria for S-SAD (sybsyndromal seasonal affective disorder).

Polysomnography

Since most available sources (5 out of 7: [5, 15, 27, 28, 29]) share the description of the winter condition, i.e. the constant darkness period, we will focus the present section on these. When no pre/post data were available [5], the difference between early autumn and winter measurements was used to qualify the winter data. The US investigations at South Pole [15,27], hence at altitude, show an increase in total sleep time (TST), an increase in sleep onset latency (SOL), an increase in the number of awakenings and movement arousals, as well as a decrease in slow wave sleep (SWS), when compared to baseline pre-departure recordings. In addition, Natani et al. [27] also evidenced a decrease in rapid eye movement (REM) sleep. These findings suggest modifications in sleep architecture that go beyond quantitative shifts in sleep and wake periods.

The sea level investigations report a more mixed picture, with [28] evidencing a progressive decrease in SWS and an increase in the number of awakenings, whereas Buguet et al. [5] reported no significant changes at all, despite their raw data showing an increase in TST, as well as a difference in SWS between winter and summer (which we will discuss in the next paragraph). Bhattacharyya et al. [29] showed a decreased TST, an increased wake after sleep onset (WASO), associated to a decreased sleep efficiency (SE), sleep efficiency, being the ration between time in bed and total sleep time, and thus being inversely related to WASO, and a decreased SWS.

To summarize the findings related to the first research question, we can conclude there are indeed consistent changes in sleep in Antarctica, despite the need for further investigations. Overall, results show poorer sleep quality and a circadian phase delay. The changes in sleep architecture seem more pronounced at altitude than at sea level, especially in the magnitude of changes regarding the number of awakenings per night, which are most likely to reflect the influence of hypoxia, as described by Fernandez-Tellez et al. [30]. A decreased SWS seems to be a common feature of all the results, albeit with different magnitude of changes in the different studies. The most consistent findings are a poor subjective sleep quality; a decreased SWS, thus indicating a lack of recovery sleep; as well as an increased sleep fragmentation, thus indicating a poorer SE.

ii) Are the changes similar or different in summer and winter?

Subjective measures

Circadian investigations showed a larger disruption of circadian rhythms in winter [17-19]. Kennaway & Van Dorp [17] did not technically include summer in their measurements (recordings from March to September), however, the magnitude of the free-running effect, which is preceded by a phase delay, is clearly related to light exposure. According to Palinkas et al. [20], there was no seasonality effect on sleep characteristics and mood, but their investigation ran from March to October, which does not include summer, and covers only the isolation period on station.

Actigraphy

Two reports include seasonality as a variable in their analyses. Collet et al. [24] showed sleep fragmentation and night time energy expenditure to be higher in summer. Steinach et al. [25] report on a much more comprehensive data set, and use regression analyses allowing to differentiate between the effect of overwintering time (as a cumulative exposure to the environment) and the effect of lack of daylight. Their results show that sleep efficiency is affected both by overwintering time and by lack of sunlight, and the same holds true when looking at daytime physical activity. The observed phase delay was more marked in winter, with all parameters (time in bed, sleep efficiency, sleep onset, sleep offset and physical activity) markedly affected.

Polysomnography

Only three of the available data sets allow for the comparison of summer and winter, i.e., the data of Shurley [15], of Paterson [28] and those of Bhattacharyya et al. [29]. Natani et al. [27] reported both summer and winter data, however, the summer data were collected upon arrival to the station, thus potentially showing more effect of the adaptation to altitude, which is why we chose to exclude them for this specific question.

The results from South Pole [15] showed a higher SOL in winter, as well as a larger number of awakenings and a larger number of movement related arousals. A part of the cohort also exhibited a decreased REM-sleep and an increased TST during winter. There is no effect of seasonality on SWS. The sea level investigations report a larger decrease of SWS during winter, which is stable according to Bhattacharyya et al. [29], and progressively decreasing further until the beginning of summer according to Paterson [28]. Furthermore, Bhattacharyya et al. [29] evidenced a larger WASO and lower SE in winter, paired with an increase in light sleep and an increase in REM. The fact that Shurley [15] did not evidence a seasonality effect on SWS, unlike Paterson [28] and Bhattacharyya [29], could be explained by the influence of chronic hypobaric hypoxia. Indeed, as we will elaborate further in a later paragraph, the effect of hypoxia might overshadow the effect of seasonality. Pattyn et al. [31] report a summer only investigation linking polysomnography, cortisol and melatonin secretion, mood and cognitive performance. Their results show a preserved cortisol rhythmicity, which the authors suggest to be due to strong social cues; and a delayed melatonin secretion, which is linked to light exposure until bedtime. About sleep, SE, SOL, SWS and light sleep are all decreased; whereas WASO and REM are increased. Furthermore, the authors show a disturbed ultradian sleep architecture, with REM sleep occurring mainly in the first part of the night and SWS later.

Overall, the majority of the reviewed articles showed a larger phase delay in winter and a more important sleep fragmentation in winter (larger number of awakenings or arousal, higher WASO). Changes in sleep stages distribution, being boiled down to a further decrease in SWS during winter, are measured only at sea level. However, regarding those differences in sleep architecture between summer and winter results, caution is warranted as the evidence base becomes even smaller. Furthermore, as shown by Steinach et al. [25], there is an influence of overwintering time, which is independent of the influence of photoperiod. Considering the operational organisation of Antarctic operations -with arrival on station during the summer-, it is currently not possible to distinguish between both. Both Steinach et al. [25] and Pattyn et al. [31] advocate for a disentangling of influences, to distinguish between social cues and photic cues, and their effect on sleep-wake behaviour and circadian physiology.

iii) Considering the nature of the changes, what are potential hypotheses regarding the causes and subtending physiological mechanisms?

As outlined previously, both the circadian and the homeostatic regulation of sleep are expected to be disturbed in Antarctica. Furthermore, the effects of psychological adaptation, be it mood disturbances or the overall effect of exposure, show to influence sleep in several reports. However, to date, no investigation shows measurements allowing to quantify these aspects of sleep regulation along with sleep architecture, which would allow to investigate the relationship between the different factors and sleep physiology, thus attempting to unveil some causal mechanisms. Considering this lack of data, we identified five areas that might help shed light on these mechanisms: chronobiology; mood; investigations regarding the link between exercise and sleep; the effect of countermeasures applied in Antarctica to counteract circadian desynchronization and sleep disturbances; and studies of sleep disorders in other areas with extreme variations of photoperiod.

Chronobiology

In the overwhelming majority of our reviewed reports, both behavioural and hormonal measures suggest a phase delay of the circadian rhythm in Antarctica, with the most robust body of evidence being for winter [9,11-14,17,18,23,25], as was first evidenced by Broadway et al. [6]. One report [17] shows free-running rhythms, however, these are preceded by a phase delay. Furthermore, the organisational parameters of this expedition were quite unique, as members could depart from a fixed social schedule, which was not the case in all other investigations mentioned.

Chronobiology studies are less scarce than sleep studies in Antarctic deployments, but their widespread use of actigraphy as a proxy measurement for sleep raises issues we will discuss later. Despite the large number of circadian variables investigated so far, ranging from sleep/activity rhythm on a behavioural basis; melatonin and its metabolite 6-sulfatoxymelatonin (aMT6s); cortisol; electrolytes; temperature; cardiovascular variables and growth hormone secretion (for a review, see [32]), none of those have been directly linked to sleep architecture, bar the recent results of Pattyn et al. [31]. Regarding circadian physiology, one can identify two main questions which can shed light on mechanisms of sleep disturbances in Antarctica. The first one is whether sleep/wake rhythms are entrained or free-running; and the second one is whether melatonin secretion is altered, advanced or delayed.

With regard to the first question, one should acknowledge that using the sleep/wake pattern to monitor circadian rhythms in settings where the social schedule is strictly regulated is problematic, for it cuts corners as a proxy measurement of the circadian pacemaker: it measures a behaviour, which furthermore is depending on social cues, and which is thus the product, or the output, of the interplay between various physiological individual regulations and the environment, both physical and social. As concluded by Yoneyama et al. [18] and confirmed by Pattyn et al. [31], the sleep-activity rhythm seems to be mostly depending on the social schedule, whereas the more direct biological measures of circadian rhythm (melatonin and temperature) were more readily linked to photoperiod. Another explanation for this discrepancy might be that the underlying delay in sleep/wake rhythm is partly counteracted by the strict social schedule, since the only report where this wasn't the case [17] shows the largest effects on sleep/wake rhythm. Further support for this hypothesis is to be found in the comparison of the magnitude of the phase delays of behavioural indices (such as sleep onset) with the magnitude of the phase delay in biological values: per our reviewed reports, phase delay of melatonin secretion is of several hours, whereas phase delay of sleep onset is an hour at most. The behavioural control over time in bed to adhere to a fixed schedule, generating a normal homeostatic sleep drive, might partly counteract the circadian phase delay.

Regarding the second question, being the secretion of melatonin, the loss of photoperiod has repeatedly been shown to have a disturbing effect on hormonal regulation (e.g. [33]). More specifically, about sleep regulation, on melatonin suppression and desynchronization [6,34]. Furthermore, as discussed previously, Yoneyama et al. [18] did not evidence a relationship between a phase-shifted melatonin rhythm and a stable rest-activity rhythm. These authors thus concluded that the phase delay they evidenced in plasma melatonin supports the explanation that melatonin and temperature rhythms are entrained by the photoperiod (hence the desynchronization), whereas rest-activity rhythm are entrained by the social schedule (hence the conserved entrainment). Their conclusion is supported by other studies, varying in the extent to which social time cues, such as a stringent work schedules, are imposed, and where the impact on the sleep-wake pattern varied accordingly [17, 32, 35]. Regarding the question raised in the present paper, about mechanisms subtending sleep disturbances occurring in Antarctica, Pattyn et al. [31] suggested that melatonin secretion disruption may be linked to changes in sleep architecture, such as the decrease in SWS. This does not imply a direct causality: it is widely accepted that melatonin only influences the timing of sleep, and not its architecture or ultradian cycles [36]. However, several elements suggest this hypothesis should be further investigated: the temporal co-occurrence of the melatonin peak and the main episodes of SWS during normal physiological sleep [37]; and the fact that both summer and winter results in Antarctica show both the timing of melatonin secretion and the amount of SWS to be affected. Melatonin secretion and SWS may be altered through a common mechanism during Antarctic deployment.

Mood disturbances

An additional element that might interact with sleep disturbances, both as cause and effect, is mood disturbances. As reviewed by Palinkas and Suedfeld [1], there is a seasonal occurrence -peaking during the winter- of clusters of symptoms ranging from sleep disturbances, to cognitive impairments, vague somatic complaints, over negative affect and interpersonal issues. These have been categorized and described in the literature as either a) the polar T3 syndrome, which mimics subclinical hypothyroidism [38]; b) the winter-over syndrome, a term coined by Strange and Youngman [39] to describe the association of mood and sleep disturbances; or, c) a subsyndromal seasonal affective disorder (S-SAD) [40]. Considering the large overlap between symptoms in these different descriptions, further research attempting to encompass the whole range of psychophysiological disturbances during prolonged stays in polar regions would allow to identify new relationships between these different clusters of symptoms. Furthermore, this raises the questions of whether sleep disturbances might be a cause, a consequence, or an influencing factor in these mood disturbances. Establishing causal links between these still ill understood mood and sleep disruptions is extremely difficult, which is true even outside extreme environments (for a review, see [41]). Indeed, even in fundamental sleep research, the common neurophysiological regulation of mood and sleep is not elucidated (e.g. [42]). As a further argument to conduct more multidisciplinary studies, research in clinical populations has shown that melatonin treatment in delayed sleep phase syndrome has an effect, not only on sleep quantity and quality, but also on the depressive symptoms [43]. Whether this effect is mediated solely by the improvement or sleep, or by the resynchronisation of circadian phase, or whether there is a specific antidepressant action of melatonin is outside the scope of the present review, but these results warrant targeting all aspects, including mood, of sleep/wake regulation in future investigations. Again, considering the reported occurrences of symptom clusters including mood disturbances [1, 38--40] during Antarctic winters, a study targeting causal elucidation of sleep disturbances should encompass a detailed evaluation of mood as well, to investigate the probable co-morbidity of both clinical presentations. An interesting caveat in this hypothesis is the fact that some reports evidence severe sleep disturbances associated to a phase delay in melatonin secretion, but with no negative effects on mood whatsoever [31]. The fact that these data were collected during a summer campaign, hence at a time when there is a continuous exposure to high intensity daylight, may suggest a more far-reaching effect of light than solely as a Zeitgeber, but also as a mood regulator, as has been described in the treatment of SAD.

Sleep, exercise and hypoxia

As pointed out in a recent review [44], sleep and exercise are mutually influencing each other, through multiple physiological and psychological pathways. Since regular moderate intensity exercise is considered beneficial for the treatment of sleep disorders [44], and since winter periods in Antarctica are considered as highly isolated and confined, a potential hypothesis for sleep disturbances during winter could be the lack of physical activity, which was evidenced by Steinach et al. [25], albeit only for his male participants; and thus, a decreased homeostatic sleep drive, which would be consistent with the decrease in SWS that is evidenced. Very few studies so far have investigated the effects of exercise on sleep in Antarctica. Collet et al. [24] found no difference in daily activity between a group wintering at the coastal station of Dumont d'Urville and the inland station Concordia. Furthermore, these authors showed that altitude (chronic exposure to hypobaric hypoxia) had more marked effects on sleep than seasonality (difference in light exposure). Indeed, the group at Concordia showed a shorter TST, a higher sleep fragmentation, and thus a lower SE compared to the Dumont d'Urville group, regardless of season. The lack of difference between both stations for daytime physical activity might indicate that the confinement hypothesis (decrease of physical activity and thus decreased homeostatic sleep drive) might not be sufficient to subtend sleep disturbances. Furthermore, Fernandez-Tellez et al. [45] described a persistence of sleep-related periodic breathing during a one year study at Concordia, which is at a pressure altitude of approximately 3800 m; and an actual adverse effect of exercise on this sleep-related periodic breathing [30]. These results mainly confirm the cautionary advice from Shurley [15], about interpreting sleep studies in Antarctica when exposure to high altitude is involved, that is, the profound physiological effects of both acute and chronic hypobaric hypoxia may overshadow the effects of extreme photoperiod, isolation and confinement. Steinach et al. [25] do show a seasonality effect on physical activity, however, it is unrelated to the sleep disturbances they measure. The authors thus conclude that the marked deterioration they see in sleep parameters cannot be ascribed to a decrease of physical activity level. So far, there is thus no support for the decreased homeostatic drive hypothesis.

Results from countermeasure investigations in Antarctica

We identified three types of countermeasures which have been implemented so far in Antarctica to counteract either circadian desynchrony, sleep disturbances or both. Exercise was discussed in the previous paragraph. One study [10] reports an intervention based on nutrition, namely 28 days of daily ornithine intake, which was shown to have a significant effect on residual morning sleepiness during a summer campaign. However, as stated by the authors, since the exact mechanism through which ornithine affects the feeling of fatigue is still unknown, there is not much to be derived from a causal point of view. The most broadly applied countermeasure so far has been light exposure, both as bright white light and blue-enriched white light. Two studies report on the use of bright white light. The first one as a two hours' exposure in the late morning (11.00-13.00), which showed to be beneficial for the recovery from a one week nightshift in the period of complete darkness [9]. The second one [13] investigates the effect of a one hour exposure in the early morning (08.30-09.30) on sleep patterns, melatonin secretion and cognitive performance. Whereas the light exposure shows a significant effect on the melatonin phase delay and cognitive performance, there are no significant effects on sleep efficiency, sleep latency, sleep fragmentation or morning alertness. This suggests light exposure to be effective in influencing the circadian pacemaker, but insufficient to be measurable on sleep quality. Regarding blue-enriched light, three studies report about its effect. Francis et al. [11] surprisingly show a deleterious effect of light exposure when comparing white and blue-enriched light with a control condition, which was replicated by Mottram et al. [12], despite being attenuated, probably, as the authors pointed out because sleep in the control condition was better than what was measured by Francis et al. However, the design of these studies put both control conditions in spring and autumn, where a day/night alternating pattern of light exposure is present at Halley, whereas the intervention was mainly over the course of the sundown period. The fact that there was no effect of the light exposure on sleep parameters might be because a potentially subtle effect is obscured by the deleterious impact of the constant darkness. Furthermore, Mottram et al. [12] did report a correlation between sleep timing (wake up and sleep start time) and overall light exposure, which, again, supports the hypothesis that light may be effective about circadian alignment, but fails to show a significant effect on sleep quality and quantity. This is further supported by the fact that Najjar et al. [14] did evidence an effect of blue enriched light exposure, not only on melatonin secretion, but also on subjective wellbeing and sleep parameters. According to their results, the exposure to blue enriched light was able to advance bed time and time of lights off, thus increasing total sleep time. However, there was no effect on sleep efficiency. To conclude, it seems light exposure is efficient to improve the phase delay observed in melatonin secretion, and to a lesser extent in sleep onset. However, sleep maintenance seems to be disturbed by another process or factor. As mentioned previously, it would be interesting to investigate the relationship between light exposure, sleep quality and mood, for the effect of light might be further reaching than solely on circadian entrainment.

Melatonin supplementation has not been investigated yet in the Antarctic environment, however, considering the results showing a circadian phase delay and an altered melatonin secretion, it is an interesting lead. Indeed, several reviews underscore the effectiveness of carefully timed melatonin for sleep disturbances associated to circadian rhythm disorders, more specifically phase delay and jet lag [46-49]. Furthermore, the introduction of pharmaceutical agonists of melatonin like ramelteon, tasimelteon or agomelatine, with slightly different pharmacokinetics in terms of receptor affinity and half-life, as well as an antidepressant action for agomelatine are promising prospects [50]. However, it might be premature to consider their use for Antarctic deployment, since the exact mechanism of the cluster psychological symptoms-sleep disturbances-circadian disruption-overall physiological adaptation is yet to be fully understood. This is further illustrated by the results from Paul et al. [51] who found no significant differences in objective measures of sleep despite a subjective improvement after melatonin supplementation in the population of a Canadian forces station in the high Arctic. An additional caveat may be ill-understood effects on sleep architecture from melatonin supplementation, like a further suppression of SWS [52].

Results from other geographical locations lacking a normal alternating daylight and night exposure

Ever since the pioneering work of Kleitman and Kleitman [53], high latitudes have been used as a natural laboratory to investigate how large changes in daylight exposure affect sleep/wake regulation. The advantage of such studies is the much larger sample available, as clearly illustrated in the largest published study investigating sleeplessness in Tromso (a Norwegian city above the Arctic circle), encompassing 14667 participants [54], and the absence of confounding variables such as isolation and confinement. However, the very absence of the other environmental and social stressors specific to Antarctic winters make results more difficult to transpose. Furthermore, as discussed by Nilssen et al. [55], the prevalence of sleep disturbances due to high latitudes might be related to the geographical origin of participants, as if native subjects had developed an evolutionary advantage, showing to be less sensitive to sleep disturbances when exposed to the changes in daylight exposure associated with higher latitudes. Both Nilssen et al. [55] and Husby and Lingjaerde [54] reported a higher prevalence of disturbed sleep in winter, mainly described as late sleep onset, hence coining the term "midwinter insomnia". In a recent study (N = 4811) carried out in Tromso on seasonal variations in sleep-wake patterns, Johnsen et al. [56] found that TST was shorter in summer, with earlier sleep onset and earlier wake up time than in winter. As in the Antarctic studies, these investigations suggest that the lack of daylight is more disruptive to the sleep-wake regulation than constant daylight, which supports the finding that changes in sleep architectures are more pronounced during winter than during summer.

Apart from high latitudes, other extreme environments share the lack of a normal daylight exposure and the social isolation and confinement dimension of Antarctic expeditions. These are spaceflight missions and the simulations to prepare a journey to Mars. Regarding actual spaceflight, the data are even sparser than in Antarctica. Gundel et al. [57] report a circadian phase delay, a lower TST and a modification of the ultradian sleep structure, with a shortened REM latency and a delayed occurrence of SWS. Dijk et al. [58] showed a circadian desynchrony because of the imposed non-24 h sleep-wake schedule, a poor subjective sleep quality and a decrease of SWS. In addition, the latter investigated whether the administration of exogenous melatonin (0.3 mg) would improve sleep, and it did not. As for simulations, Basner et al. [59] investigated sleep and activity through actigraphy and questionnaires in the longest simulation study to date (Mars 520). Their data show several markers of sleep disturbances: a desynchronization of the sleep-wake rhythm and reductions in perceived sleep quality. These effects do not improve over time, quite the contrary, since time effects reveal an increasing sedentariness of the crew, which is termed by the author as hypokinesis and behavioural torpor. Another noteworthy finding from this investigation is the high level of interindividual differences and thus of vulnerability of individuals to the disturbances caused by isolation and confinement. This confirms the results in Antarctic winters from Yoneyama et al. [18], Fernandez-Tellez et al. [30] and Chen et al. [26]. Another isolation study, of a duration of 105 days, relates sleep disturbances to stress, as EEG patterns showing sleep disturbances are associated to cortisol levels [60]. More specifically, the authors suggest their findings of a physiological relationship between the cortisol production during a day and sleep the following night may indicate a causal link between stress and sleep disturbances, as was suggested in other research (e.g. [61,62]). This further confirms the need for multidisciplinary investigations encompassing mood. However, as the authors point out, the relationship is complex, since sleep disruption causes a stress response. The interaction of sleep and stress is not a novel concept, but is an important link to keep in mind when discussing sleep and extreme environment, which had already been advocated by Buguet et al. [63].

Choice of the sleep measurement method

Considering the paucity of knowledge with regard to the accurate description of sleep disturbances in Antarctica, this research field still needs detailed in-depth studies of sleep physiology and thus is not yet ready for replacing polysomnography with actigraphy. Indeed, even though actigraphy offers an alternative to quantify sleep in a much more cost-effective way, both in terms of hardware investment and in terms of data analysis, which allows to collect substantially larger data sets, as is clear from the investigation of Steinach et al. [25], we still lack the basic knowledge of the pathophysiology of "polar insomnia" that would allow us to target interventions. Whereas we are in no way advocating against the potential benefits of the current "big data" evolution [64,65], we can only conclude that, for now, Antarctica still requires some fundamental sleep research, as was advocated in their conclusions by both Najjar et al. [14] and Steinach et al. [25]. It seems there is a gap in the evolution of sleep research in Antarctica: considering the small samples involved, one can hardly use a "Big Data" approach only, and the fact that the psychophysiological response to exposure to the Antarctic environment is still incompletely described warrants the use of more in-depth investigation techniques. As reviewed by Van de Water et al. [66], wrist actigraphy is the most common method for sleep evaluation outside of a laboratory setting. However, as emphasized by these authors, wrist actigraphy tends to overestimate sleep, especially in a population with poor sleep quality. Furthermore, it is advocated that the specificities of the population and potential disorders are considered when choosing both the device and the scoring algorithm. Moreover, although a series of studies appear to promote the use of actigraphy as a satisfying alternative to polysomnography [67-70], on a more detailed level, most studies keep on reporting important blind spots in the actigraphical data about the measurement of sleep efficiency [71-73], sleep onset latency [69,73,74], total sleep time [71,72] and waking epochs [68,72]. This is especially relevant since those parameters showed to be disturbed in Antarctica. Several authors have argued that caution was indeed warranted not to overestimate the sleep variables, even more so in more highly sleep disturbed populations [67,71]. Furthermore, several authors also argue that actigraphy should be adjusted for individual differences [69,73,75]. As reviewed in the current practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders [76], actigraphy provides an acceptable surrogate estimate of sleep patterns in circadian disorders. However, there is no evidence to date that sleep disruptions in Antarctica are limited to circadian issues. To summarize, the main caveat about the use of actigraphy in Antarctic sleep studies is that, so far, there is no consensus regarding the type of sleep disturbances observed in terms of sleep architecture and sleep regulation.

Conclusion

The present review has allowed to draw a current state of the art about two of the three questions identified in the introduction. There are indeed consistent changes in sleep in Antarctica. Bringing together data from subjective assessment, actigraphy and polysomnography, we can summarize the observed sleep disturbances as i) a delay in sleep onset and awakening; ii) a poor sleep efficiency due to both an increased sleep onset latency and a higher fragmentation; iii) a reciprocal relationship between sleep and mood disturbances; and iv) a lack of SWS. It should be stressed that most of the data are collected in the period of isolation on stations, commonly called winter, and ranging from February/March to October/November. Hence, the available data to describe potential differences between summer and winter are even sparser. The observed disturbances (decreased SWS and increased sleep fragmentation, thus decreased SE; circadian phase delay of both biological and behavioural measures) seem even more pronounced in winter. However, the influence of seasonality during an Antarctic stay goes further than the variation in daylight exposure. The summer is a 3 months' period during which stations are quite bustling with activity, with a turnover of people, an extremely busy schedule, longer working hours, demanding physical tasks to be performed outside, and for some important recreation possibilities. The winter, on the other hand, is indeed what most people expect when discussing overwintering: a long stretch of monotonous time in isolation in a closed community, with little to no possibility of evacuation, and limited outside activities. Hence it is quite difficult to interpret potential differences between summer and winter, because of the obvious confound. Summer is the period of constant illumination, but also of a totally different social setting. This should not imply it is useless to perform experiments during the summer, but that these social circumstances should be documented as well.

The third question we identified, namely "*Considering the nature of the changes, what are potential hypotheses regarding the causes and subtending physiological mechanisms?*" could only be speculated upon, considering the lack of direct data to support an evidence-based answer. Most reports we reviewed evidenced a circadian phase delay, however, to date, only a summer investigation linked its effects on sleep architecture in the specific context of an Antarctic deployment [31], where it is clear several factors interact to adversely influence sleep. Per the chronobiology studies, we could expect the altered melatonin secretion to adversely influence sleep, not only in terms of timing (which could subtend the disturbed SOL or WASO), but also in terms of architecture. The ultradian structure of sleep has been insufficiently documented so far. Results from space [51] and an Antarctic summer campaign [31] indicate a disturbed ultradian rhythm, with a delayed occurrence of SWS and an earlier occurrence of REM sleep. In addition, despite the loss of normal exposure to daylight and night in a 24 h epoch, which is considered as the main Zeitgeber, even the circadian disruption is not as clear cut as it seems. Several reports indicate the phase delay of melatonin, however, other measures seem synchronized, like cortisol [31] or the sleep-wake rhythm [18]. Sleep and wake differ from other circadian variables because they are under voluntarily control, highly dependent on social cues, and can themselves act as cues to synchronize other parameters. Furthermore, the discrepancy between “social time” and “melatonin time” may result in a desynchronized sleep, which might be one of the factors subtending the poor sleep quality. The effects on the ultradian structure of sleep may be an expression of this desynchronized sleep. To summarize, there is a circadian disruption present, which has been described so far as a phase delay, however, the full scope of its interaction with sleep still warrants further research to be understood.

Mood disturbances are highly likely to co-occur with sleep disturbances, as has been evidenced by the review of the different symptom clusters described in relation to Antarctic deployment, which all encompass both mood disturbances and sleep disruption. Furthermore, data from a 105 days’ simulation of a Mars expedition [60] made the link between the stress to which participants were exposed and their sleep EEG. Whether these are respectively causes or consequences of each other will be extremely difficult to find out, just as in a normal -non-extreme- environment, both within normal populations and patient groups. However, their evaluation should be part of future investigations, as it is highly likely these play an important part in the overall psychophysiological adaptation to this extreme environment.

As for physical activity, even though physical activity is indeed decreased in winter, there does not seem to be a relationship with sleep disturbances. Our review thus allows to discard the hypothesis that a decreased homeostatic drive might cause the sleep decrements observed in Antarctica. However, exercise might have beneficial effects on sleep in Antarctica, as it is recommended for the treatment of sleep disorders [44], provided the station is not at altitude, as regular exercise seems to exacerbate the deleterious effects of chronic hypobaric hypoxia on sleep and breathing [30].

Other potential countermeasures include light exposure, nutrition and melatonin supplementation. Light exposure, especially blue enriched light, seems the most promising one. However, its effects on sleep architecture and mood have not been documented in Antarctica.

For investigations in Antarctica, considering the paucity of knowledge so far, it is impossible to define whether a surrogate to PSG would be sufficiently accurate or not. Actigraphy thus definitely is a useful tool in such applied setting, but the detailed investigation of sleep architecture would still require additional investigations with PSG. The results of the present review of the literature reveal the difficulties in drawing general conclusions about human sleep in Antarctic regions. The first one is the very small number of subjects these conclusions can be based upon. Apart from the obvious methodological caveat, this is further emphasized by several reports, which identify a great interindividual variability in participants' adaptation to the conditions of isolation, confinement, lack of daylight exposure or chronic hypoxia [18, 26, 45, 59], suggesting predispositions that have not been investigated so far. Furthermore, considering the geographical and social differences between stations, results cannot readily be pooled. From a physiological adaptation view, the main obstacle for this is the effect of chronic hypobaric hypoxia at altitude stations. This was emphasized by Shurley [15] as well, when he stressed that the major physiological changes evidenced by the biomedical research of the Oklahoma Project (large scale psychophysiological investigation of human adaptation at South Pole) were related to high-altitude hypoxia. Extreme environments research often has to deal with numerous confounds, however, the magnitude of the physiological changes due to altitude-related hypoxia (for a review, see [77]) are such that these effects may well obliterate other subtler influences related to long duration isolation and confinement, mood disturbances or the lack of daylight exposure. Joern et al. [4] and Natani et al. [27] already discussed this to interpret their results. However, the decrease in SWS observed in other stations shows this effect to be caused by more than the chronic exposure to hypobaric hypoxia. The only experimental approach allowing to disentangle those effects would be to foresee similar measurements at both an altitude station and at sea level, with similar mission characteristics. Another caveat is related to a historical shift in life on stations. During the last decade, most operators have introduced 24/7 data connections freely available to wintering staff. The data reviewed in the current paper stems from an age where this communication was not readily available, bar a few exceptions. The access to mainstream social media, and the continuous contact with home may have several effects, both in terms of psychological adaptation and in terms of timing of social life. Whereas it can currently only be speculated upon, it is certainly necessary to document this aspect in future research. Another general issue typical for this field of investigation is of methodological nature, i.e. the lack of robust control measurements in some reports. Indeed, when there are no pre-deployment measures available, interpretation of sleep parameters is rendered speculative. Lastly, as has been identified in other extreme environments research such as aviation and space medicine [78], data on female participants are fairly inexistent. Steinach et al. [25] were the first to address this with their report, however, it took seven consecutive years of data recording to be able to do so. All the polysomnographic data reviewed in the present paper stem from male cohorts. This is partly due to historic roots (in the past most national Antarctic programs did not allow for women to be part of winter-over crews, which nowadays carries on with a usually low percentage of females among overwintering crews), but can also reflect a bias chosen by the investigator to not introduce an additional confound in the data due to an imbalanced gender distribution. However, as has been recognized by some major funding bodies (such as the FP7 from the EU), this male bias introduces an important discrimination in the scientific evidence, since it is only valid for one half of the population.

To conclude, one can thus only stress the need for broader multidisciplinary sleep research in Antarctica. Whereas identifying changes in sleep architecture is valuable to confirm the picture emerging from the present review, or to enrich it; a definite need exists, both for fundamental research and for operationally relevant investigations, to shed light on the subtending mechanisms of the identified disturbances. Indeed, considering the underlying changes in sleep-wake regulation, as well as considering a broader picture of the psychophysiological adaptation (including mood disturbances, but also potential metabolic disruptions and changes in gene expression), would allow new insights in the complex regulation of these processes. From an operational point of view, pinpointing causes to the sleep disturbances will allow to investigate potential interventions in a more meaningful way, thus offering ways to improve both safety and well-being of deployed personnel.

Practice points

- The main sleep disturbances evidenced in Antarctic deployments are a poor sleep efficiency, delayed sleep onset, a lack of restorative sleep and a lack of SWS.

- Actigraphy represents an insufficient proxy for sleep investigation in Antarctica, considering the disturbances of SE.

- Sleep disturbances are worse during the Antarctic winter, which is the period of isolation and constant darkness. This is confirmed by results on much larger samples from Arctic regions.

- Altitude, and thus the exposure to chronic hypobaric hypoxia, might have much larger effects on sleep architecture than the extreme variation of daylight exposure.

- Potential causal mechanisms or influences that have been identified are a delayed secretion of melatonin and psychophysiological adaptation disorders such as the "polar T3 syndrome" or the "winter-over syndrome".

Research agenda

Future investigations of sleep in Antarctica should

- Adopt a multidisciplinary methodology, to target all influences of sleep, to identify potential causal mechanisms for the occurring sleep disturbances. This means a quantification of physical activity; mood and circadian rhythms, more particularly melatonin secretion; metabolic disruption and gene expression.

- Considering the wide variation in station environments, and even within stations between summer and winter seasons, the geographical and social parameters should be documented as well. This includes the availability and use of social media and communication with home.

- Once potential causal mechanisms are identified, intervention studies during Antarctic deployment should target these specific mechanisms (e.g. exercise regimens, light exposure or melatonin supplementation), and intervention effects should be measured in the same multidisciplinary way as causal investigations.

- Gender differences should be investigated, to build a knowledge base that would benefit all deployed personnel.

- Sleep research at altitude stations should ideally be planned in parallel with sea level investigation in stations that are similar regarding crew size, landscape and latitude.

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6. References

1. *Palinkas LA, Suedfeld P. Psychological effects of polar expeditions. Lancet. 2008; 371:153-163.
2. Guly HR. Psychology during the expeditions of the heroic age of Antarctic explorations. Hist Psychiatry. 2014;23(2):194-205.
3. Taylor IM. Medical experiences at McMurdo Sound. In: Horvath S, editor. Cold injury. New York: Macy; 1960:117-140.
4. Joern AT, Shurley JT, Brooks RE, Guenter CA, Pierce CM. Short term changes in sleep pattern on arrival at the south polar plateau. Arch Int Med. 1970; 125: 649-654.
5. *Buguet A, Rivolier J, Jouvet M. Human sleep patterns in Antarctica. Sleep. 1987;10 (4): 374-382.
6. Broadway J, Arendt J, Folkard S. Bright light phase shifts the human melatonin rhythm during the Antarctic winter. Neurosci Letters. 1987;79:185-189.
7. Bhargava R, Mukerji S, Sachdeva U. Psychological impact of the Antarctic winter on Indian expeditioners. Env Beh. 2000; 32:111-127.
8. Friborg O, Bjorvatn B, Amponsah B, Pallesen S. Associations between seasonal variations in day length (photoperiod), sleep timing, sleep quality and mood: a comparison between Ghana (5°) and Norway (69°). J Sleep Res. 2012;21: 176-184.
9. Ross JK, Arendt J, Horne J, Haston W. Night-Shift Work in Antarctica: Sleep Characteristics and Bright Light Treatment. Phys & Beh. 1995;57(6):1169-1174.
10. Horiuchi M, Kanesada H, Miyata T, Watanabe K, Nishimura A, Kokubo T et al. Ornithine ingestion improved sleep disturbances but was not associated with

correction of blood tryptophan ration in Japanese Antarctica expedition members during summer. Nut Res. 2013;33: 557-564.

11. Francis G, Bishop L, Luke C, Middleton B, Williams P, Arendt J. Sleep during the Antarctic winter: preliminary observations on changing the spectral composition of artificial light. J Sleep Res. 2008;17:354-360.
12. Mottram V, Middleton B, Williams P, Arendt J. The impact of bright artificial white and 'blue-enriched' light on sleep and circadian phase during the polar winter. J Sleep Res. 2011;20:154-161.
13. Corbett RW, Middleton B, Arendt J. An hour of bright white light in the early morning improves performance and advances sleep and circadian phase during the Antarctic winter. Neurosc Lett. 2012;525:146-151.
14. *Najjar RP, Wolf L, Taillard J, Schlangen LJM, Salam A, Cajochen C et al. Chronic artificial blue-enriched white light is an effective countermeasure to delayed circadian phase and neurobehavioral decrements. PLOS ONE; 2014;9(7):1-10.
15. *Shurley JT. Physiological research at U.S. stations in Antarctica. In: Gunderson EKE, editor. Human adaptability to Antarctic conditions. Washington: American Geophysical Union; 1974:71-87.
16. Bogolovskii MM. Polar insomnia on the Antarctic continent [letter]. Lancet. 1974; 1 (7856):503-504.
17. Kennaway DJ, Van Dorp CF. Free-running rhythms of melatonin, cortisol, electrolytes, and sleep in humans in Antarctica. Am J Physiol. 1991; 65: 823-828.
18. Yoneyama S, Hashimoto S, Honma K. Seasonal changes of human circadian rhythms in Antarctica. Am J Physiol. 1999;277: R1091-R1097.

19. Usui A, Obinata I, Ishizuka Y, Okado T, Fukuzawa H, Kanba S. Seasonal changes in human sleep-wake rhythm in Antarctica and Japan. Psychiatry Clin Neurosci. 2000; 54:361-362.

20. *Palinkas LA, Houseal M, Miller C. Sleep and mood during a winter in Antarctica. Int J Circumpolar Health. 2000;59(1): 63-73.

21. Weymouth W, Steel G. Sleep patterns during an Antarctic field expedition. Mil Med. 2013;178(4); 438-444.

22. Tassino B, Horta S, Santana N, Levandovski R, Silva A. Extreme late chronotypes and social jetlag challenged by Antarctic conditions in a population of university students from Uruguay. Sleep Sci. 2016;9:20-28.

23. Gander PH, Macdonald JA, Montgomery JC, Paulin MG. Adaptation of sleep and circadian rhythms to the Antarctic summer: a question of Zeitgeber strength. Avn, Space & Env Med. 1991;62(11);1019-1025.

24. Collet G, Mairesse O, Cortoos A, Tellez HF, Neyt X, Peigneux P et al. Altitude and seasonality impact on sleep in Antarctica. Aerosp Med Hum Perform. 2015;86(4):1 – 5.

25. *Steinach M, Kohlberg E, Maggioni MA, Mendt S, Opatz O, Stahn A et al. Sleep quality changes during overwintering at the German Antarctic stations Neumayer II and III: The gender factor. PLOS ONE. 2016:11(2); e0150099.

26. Chen N, Wu Q, Xiong Y, Chen G, Song D, Xu C. Circadian Rhythm and Sleep During Prolonged Antarctic Residence at Chinese Zhongshan Station. Wilderness Environ Med. 2016;27(4):458-67.

27. Natani K, Shurley JT, Pierce CM, Brooks RE. Long-Term Changes in Sleep Patterns in Men on South-Polar-Plateau. Arch Intern Med. 1970;125(4):655-&.

28. *Paterson RAH. Seasonal reduction of slow wave sleep at an Antarctic coastal station. Lancet. 1975; 1(7904), 468-469.
29. *Bhattacharyya M, Pal MS, Sharma YK, Majumdar D. Changes in sleep patterns during prolonged stays in Antarctica. Int J Biometeorol. 2008;52(8):869-79.
30. Fernandez-Tellez H, Morrison SA, Neyt X, Mairesse O, Piacentini MF, Macdonald-Nethercott E et al. Exercise during short and long-term continuous exposure to hypoxia exacerbates sleep-related periodic breathing. Sleep. 2015; 39(4): 773-783.
31. Pattyn N, Mairesse O, Cortoos A, Marcoen N, Neyt X, Meeusen R. Sleep during an Antarctic summer expedition: new light on "polar insomnia". J Appl Physiol (1985). 2017:jap 00606 2016.
32. *Arendt J. Biological rhythms during residence in polar regions. Chronobiol Int. 2012; 29 (4):379-394.
33. Olson JJ. Antarctica: a review of recent medical research. TRENDS in Pharmacological Sciences. 2002; 23 (10): 487-490
34. Leppäluoto J, Sikkilä K, Meyer-Rochow VB, Hassi J. Low melatonin secretion associates with albedo in circumpolar environments. J Pineal Res. 2003; 35: 158-162.
35. Weitzman ED, de Graaf AS, Sassin JF, Hansen T, Goltlibsen OB, Perlow M et al. Seasonal patterns of sleep stages and secretion of cortisol and growth hormone during 24 hour periods in northern Norway. Acta Endocrinol. 1975; 78:65-76.
36. Arendt J. Melatonin and human rhythms. Chronobiol Int. 2006; 23 (1 & 2): 21-37.
37. Kryger MH, Roth T, Dement WC. Principles and practice of sleep medicine. 5th edition. Philadelphia: Saunders; 2011.

38. Reed HL, Reedy KR, Palinkas LA, Van Do N, Finney NS, Case HS et al. Impairment in cognitive and exercise performance during prolonged Antarctic residence: effect of thyroxine supplementation in the Polar triiodothyronine syndrome. J Clin Endocrinol Metab. 2001; 86:110-116.
39. Strange RE, Youngman SA. Emotional aspects of wintering over. Antarct J US. 1971; 6:255-257.
40. Palinkas LA, Houseal M, Rosenthal NE. Subsyndromal seasonal affective disorder in Antarctica. J Nerv Ment Dis. 1996; 184:530-534.
41. Lustberg L, Reynolds, CF. Depression and insomnia: questions of cause and effect. Sleep Med Rev. 2000; 4(3):253-262.
42. Luca A, Luca M, Calandra C. Sleep disorders and depression: brief review of the literature, case report, and nonpharmacologic interventions for depression. Clin Interven Aging. 2013: 8;1033-1039.
43. Rahman SA, Kayumov L, Shapiro CM. Antidepressant action of melatonin in the treatment of Delayed Sleep Phase Syndrome. Sleep Med. 2010; 11:131-136.
44. Chennaoui M, Arnal PJ, Sauvet F, Léger D. Sleep and exercise: A reciprocal issue? Sleep Med Rev. 2015; 20: 59-72.
45. *Fernandez-Tellez H, Mairesse O, Macdonald-Nethercott E, Neyt X, Meeusen R, Pattyn N. Sleep-related Periodic Breathing Does Not Acclimatize to Chronic Hypobaric Hypoxia: A 1-Year Study at High Altitude in Antarctica. Am J Resp Crit Care Med. 2014; 190 (1): 114-116.
46. Buscemi NV, B.; Pandya, R.; Hooton, N.; Tjosvold, L.; Hartling, L.; Baker, G. et al. Melatonin for treatment of sleep disorders. In: Quality AfHRa, editor. Rockville, MD: University of Alberta Evidence-based Practice Center; 2004.

47. Skene DJ, Arendt J. Human circadian rhythms: physiological and therapeutic relevance of light and melatonin. Annals of clinical biochemistry. 2006;43(Pt 5):344-53.

48. Srinivasan V, Singh J, Pandi-Perumal SR, Brown GM, Spence DW, Cardinali DP. Jet lag, circadian rhythm sleep disturbances, and depression: the role of melatonin and its analogs. Adv Ther. 2010;27(11):796-813.

49. Costello RB, Lentino CV, Boyd CC, O'Connell ML, Crawford CC, Sprengel ML, et al. The effectiveness of melatonin for promoting healthy sleep: a rapid evidence assessment of the literature. Nutr J. 2014;13:106.

50. Williams WP, 3rd, McLin DE, 3rd, Dressman MA, Neubauer DN. Comparative Review of Approved Melatonin Agonists for the Treatment of Circadian Rhythm Sleep-Wake Disorders. Pharmacotherapy. 2016;36(9):1028-41.

51. Paul MA, Love RJ, Hawton A, Brett K, McCreary DR, Arendt J. Sleep deficits in the High Arctic summer in relation to light exposure and behaviour: use of melatonin as a countermeasure. Sleep medicine. 2015;16(3):406-13.

52. Arbon EL, Knurowska M, Dijk DJ. Randomised clinical trial of the effects of prolonged-release melatonin, temazepam and zolpidem on slow-wave activity during sleep in healthy people. J Psychoparm. 2015;29(7):764-776.

53. Kleitman N, Kleitman E. 1953, in Czeisler C. Light and the human circadian pacemaker. CIBA Foundation Symposium: Circadian clocks and their adjustment., p 263. Wiley & Sons, 2008.

54. Husby R, Lingjaerde O. Prevalence of reported sleeplessness in northern Norway in relation to sex, age and season. Acta Psychiatr Scand; 1990; 81 (6): 542-547.

55. Nilssen O, Lipton R, Brenn T, Hoyer G, Bioko E, Tkatchev A. Sleeping problems at 78 degrees north: the Svalbard Study. Acta Psychiatr Scand. 1997; 95: 44-48.

56. Johnsen MT, Wynn R, Allebrandt K, Bratlid T. Lack of major seasonal variations in self reported sleep-wake rhythms and chronotypes among middle aged and older people at 69 degrees North: The Tromso Study. Sleep Med. 2013; 14: 140-148.

57. Gundel A, Polyakov VV, Zulley J. The alteration of human sleep and circadian rhythms during spaceflight. J Sleep Res. 1997;6(1):1-8.

58. Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, et al. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol Regul Integr Comp Physiol. 2001;281(5):R1647-64.

59. Basner M, Dinges DF, Mollicone D, Ecker A, Jones CW, Hyder EC, et al. Mars 520-d mission simulation reveals protracted crew hypokinesis and alterations of sleep duration and timing. Proceedings of the National Academy of Sciences of the United States of America. 2013;110(7):2635-40.

60. Gemignani A, Piarulli A, Menicucci D, Laurino M, Rota G, Mastorci F, et al. How stressful are 105 days of isolation? Sleep EEG patterns and tonic cortisol in healthy volunteers simulating manned flight to Mars. Int J Psychophysiol. 2014;93(2):211-9.

61. Kecklund G, Axelsson J. Health consequences of shift work and insufficient sleep. BMJ. 2016;355:i5210.

62. Harvey CJ, Gehrman P, Espie CA. Who is predisposed to insomnia: a review of familial aggregation, stress-reactivity, personality and coping style. Sleep medicine reviews. 2014;18(3):237-47.

63. Buguet A, Cespuglio R, Radomski MW. Sleep and stress in man: an approach through exercise and exposure to extreme environments. Can J Physiol Pharmacol. 1998;76(5):553-61.

64. Mayer-Schonberger V, Cukier K. Big Data. A Revolution That Will Transform How We Live, Work, and Think. New York (NY): Houghton Mifflin Harcourt; 2013.

65. Big Data. 2014 [cited 2014 August 4]. Available from http://www.nature.com/news/specials/bigdata/index.html

66. Van de Water AT, Holmes A, Hurley DA. Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography-a systematic review. J Sleep Res. 2011;20(1 Pt 2):183-200.

67. Blackwell T, Redline S, Ancoli-Israel S, Schneider JL, Surovec S, Johnson NL, et al. Comparison of sleep parameters from actigraphy and polysomnography in older women: The SOF study. Sleep. 2008;31(2):283-91.

68. de Souza L, Benedito-Silva AA, Pires MLN, Poyares D, Tufik S, Calil HM. Further validation of actigraphy for sleep studies. Sleep. 2003;26(1):81-5.

69. Lichstein KL, Stone KC, Donaldson J, Nau SD, Soeffing JP, Murray D, et al. Actigraphy validation with insomnia. Sleep. 2006;29(2):232-9.

70. Mccall C, Mccall WV. Comparison of actigraphy with polysomnography and sleep logs in depressed insomniacs. J Sleep Res. 2012;21(1):122-7.

71. Beecroft JM, Ward M, Younes M, Crombach S, Smith O, Hanly PJ. Sleep monitoring in the intensive care unit: comparison of nurse assessment, actigraphy and polysomnography. Intens Care Med. 2008;34(11):2076-83.

72. Paquet J, Kawinska A, Carrier J. Wake detection capacity of actigraphy during sleep. Sleep. 2007;30(10):1362-9.

73. Signal TL, Gale J, Gander PH. Sleep measurement in flight crew: Comparing actigraphic and subjective estimates to polysomnography. Aviat Space Envir Md. 2005;76(11):1058-63.

74. Tonetti L, Pasquini F, Fabbri M, Belluzzi M, Natale V. Comparison of two different actigraphs with polysomnography in healthy young subjects. Chronobiol Int. 2008;25(1):145-53.

75. Jean-Louis G, Kripke DF, Cole RJ, Assmus JD, Langer RD. Sleep detection with an accelerometer actigraph: comparisons with polysomnography. Physiol Behav. 2001;72(1-2):21-8.

76. Morgenthaler T, Alessi C, Friedman L, Owens J, Kapur V, Boehlecke Bet al. Practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders: an update for 2007. Sleep. 2007;30(4):519-29.

77. West JB, Schoene RB, Luks AM, Milledge JS. High Altitude Medicine and Physiology. 5th edition. Boca Raton (FL): CRC Press; 2012.

78. Mitchell J, Kristovics A, Vermeulen LP. Another empty kitchen: gender issues on the flight deck. In: Bridges D, Neal-Smith J, Mills AJ, editors. Absent Aviators. Farnham (UK):Ashgate; 2014.

79. https://www.nasa.gov/mission_pages/icebridge/multimedia/fall11/antarctica-US.html [downloaded July 20th 2016]

80. https://www.comnap.aq/Publications/Comnap%20Publications/Forms/Publications.aspx?Category=Maps%20and%20Charts [downloaded July 20th 2016]

7. Figures captions

Figure 1: Map of Antarctica showing the relative size of the continent [79]

Figure 2: Map of Antarctica showing the different stations [80]

8. Tables

Table I: *Chronological Overview of studies that made use of subjective measures ([1] S = Summer; W = Winter).*

	Subjects		Environment						Recording information		Miscellaneous
Reference	N and gender	Station	Altitude (in m)	Crew size winter	Latitude	Months constant light/ darkness	S/W[1]	Landscape	Habituation	Total number of nights + timing	Results and/or remarks
Kennaway & Van Dorp 1991 [17]	4 (3 M; 1 W)	Cape Evans (NZ)	0	4	77°	4	W	Coastal station	NA	Continuously	Chronobiology investigation including cortisol, melatonin and electrolytes measures.
Ross et al. 1995 [9]	14 M	Halley (UK)	0	15	75°	3.5	W	Buried base	NA	2 x 5 weeks	Intervention study investigating recovery from 1 week night shift with white light exposure vs dim red light exposure.
Yoneyama et al. 1999 [18]	9 M	Dome Fuji (Japan)	3810	15	77°	4	S&W		NA	Continuously	Chronobiology investigation including actigraphy and rectal temperature (n=3) and melatonin (n=9); heavy physical duties for all crew members.
Usui et al. 2000 [19]	8 M	Syowa (Japan)	0	28	69°	2	S&W	Coastal station	NA	Continuously	Chronobiology investigation of sleep-wake rhythm comparing a group in Antarctica and a group in Japan.
Palinkas et al. 2000 [20]	91	MacMurdo, South Pole, Palmer (US)	NA	NA	NA	NA	W	NA	NA	NA - Monthly	Investigation of the seasonal variation in sleep and mood across the 3 stations of the US Antarctic Research program.

Weymouth & Steel 2012 [21]	14	Scott (NZ)	0	10	77°	4	S	Coastal station	Pre-measures	4 upon arrival	Investigation of sleep patterns on station and during a field expedition.
Horiuchi et al. 2013 [10]	11 (10 M; 1 W)	Syowa (Japan	0	28	69°	2	S	Coastal station	Pre-measures	3 - Monthly questionnaires	Intervention study investigating ornithine supplementation.
Tassino et al. 2016 [22]	17 (6 M; 11 W)	Artigas (Uruguay)	17	9	62°	<1	S	Coastal station	Pre- & Post measures	9 x sleep logs	Influence of chronotype on adaptation to Antarctic summer.

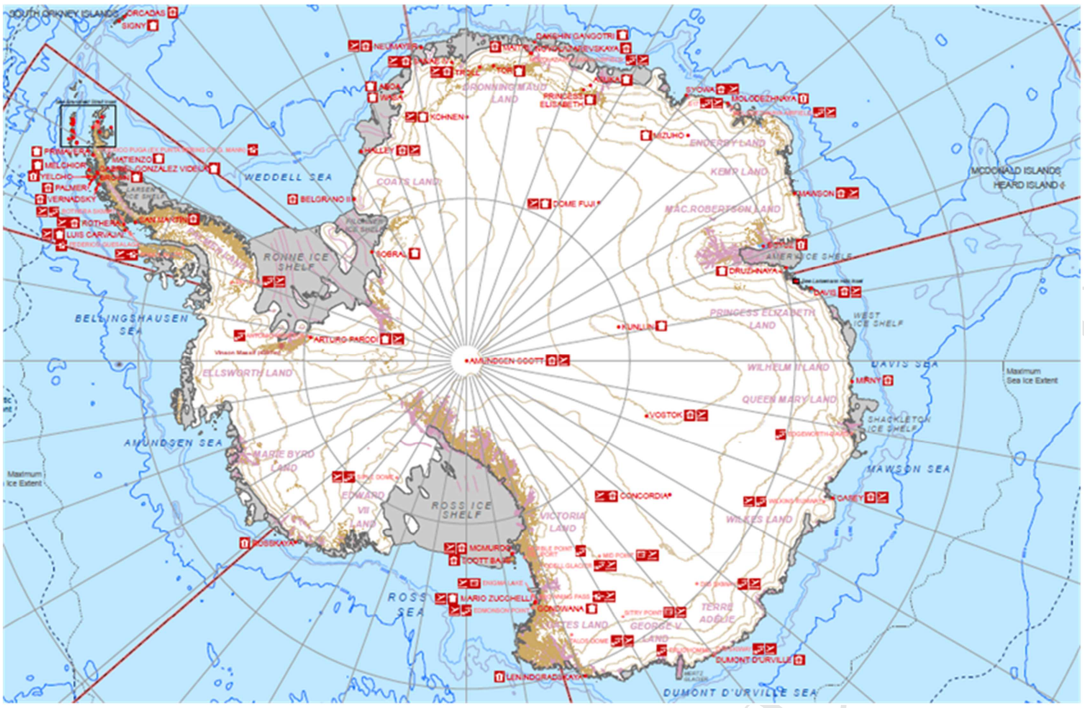
Table II: *Chronological overview of studies that made use of actigraphy measures ([1] S = Summer; W = Winter).*

	Subjects		Environment						Recording information		Miscellaneous
Reference	N and gender	Station	Altitude (in m)	Crew size winter	Latitude	Months constant light/ darkness	S/W[1]	Landscape	Habituation	Total number of nights + timing	Results and/or remarks
Gander et al. 1991 [23]	3 M	Scott (NZ)	0	10	77°	3.5	S	Coastal station	Pre-measures	13 x 24 hrs Consecutive upon arrival	Sleep logs and actigraphy.
Francis et al. 2008 [11]	10 (9M; 1W)	Halley	0	15	75°	3.5	W	Coastal station, no wildlife or landscape variation	NM	continuously	Sleep diaries and actigraphy (results of sleep diaries not presented); intervention study comparing white light and blue enriched light
Mottram et al. 2011 [12]	15 (10 M; 5 W)	Halley	0	15	75°	3.5	W	Coastal station, no wildlife or landscape variation	NM	continuously	Sleep diaries (results not presented) and actigraphy; intervention study comparing white light and blue enriched light
Corbett et al. 2012	9 (8 M; 1 W)	Halley (UK)	0	15	75°	3.5	W	Coastal station, no wildlife or	NM	continuously	Sleep diaries (results not presented) and actigraphy;

[13]								landscape variation			intervention study to bright light exposure in morning.
Najjar et al. 2014 [14]	10 (8 M; 1 W)	Concordia (France/Italy)	3200	15	75°	3.5	W	White desert	NA	Continuously	Sleep diaries and actigraphy; intervention study to exposure u blue-enriched white light
Collet et al. 2015 [24]	26 (21 M; 5 W)	Concordia (France/Italy) Dumont d'Urville	Mixed	Mixe d	Mixed	Mixed	S & W	Mixed	NA	24 hrs once in summer and once in winter	Actigraphy: only one recording for each season; investigates effect of altitude and seasonality
Steinach et al. 2016 [25]	54 (37 M; 17 W)	Neumayer (Germany)	0	9	70°	2.5	S&W	Neumayer II: buried station; Neumayer III: above ground	NM	Continuously	Multicampaign study reporting the influence of gender. No outside recreation in winter.
Chen et al. 2016 [26]	11 M	Zhongshan (China)	10	17	69°	2	W	Hilly terrain	Pre-measures	14 days for each measurement	Measures Before deployment; Before winter; Mid-winter; End of winter

Table I: Chronological overview of studies that made use of polysomnography measures ([1] S = Summer; W = Winter).

	Subjects	Environment							Recording information		Miscellaneous
Reference	N and gender	Station	Altitude (in m)	Crew size winter	Latitude	Months constant light/ darkness	S/W[1]	Landscape	Habituation	Total number of nights + timing	Results and/or remarks
Joern et al. 1970 [4]	2 M	South Pole (US)	2800	75	90°	5.5	S	White desert	yes	7 nights - consecutive upon arrival	Recordings upon arrival: no habituation period on station; 1 subject suffering from altitude sickness
Natani et al. 1970 [27]	4 M	South Pole (US)	2800	75	90°	5.5	S&W	White desert	Yes; Pre/post recordings	4 - every 3 months	
Shurley 1974 [15]	20 M	South Pole (US)	2800	75	90°	5.5	S&W	White desert	Yes; Pre/post recordings	4 - every 3 months	Most comprehensive data set; not published in indexed journal
Paterson 1975 [28]	10 M	Halley (UK)	0	15	75°	3.5	S&W	Buried base	Yes	9 - monthly	
Buguet et al. 1987 [5]	8 M	Dumont d'Urville (France)	0	26	66°	None	W	Coastal station	Yes	8 - monthly	Outside activities even during winter; selection bias: 8 subjects chosen from the crew of 28 based on their good sleeping habits
Bhattacharya et al. 2008 [29]	6 M	Maitri (India)	260	25	70°	2.5	S&W	Mountainous region	Yes; Pre measurements	12 - monthly	
Pattyn et al. 2017 [31]	9 M	Princess Elizabeth (Belgium)	1382	NA	71°	2.5	S	Mountainous region	Yes	1 in summer	Between-subject design with matched control group


SOUTH ORKNEY ISLANDS
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RONNE ICE SHELF
BELLINGSHAUSEN SEA
AMUNDSEN SEA
ELLSWORTH LAND
MARIE BYRD LAND
ROSS ICE SHELF
ROSS SEA
VICTORIA LAND
AMUNDSEN-SCOTT
VOSTOK
CONCORDIA
DOME FUJI
KOHNEN
HALLEY
BELGRANO II
SOBRAL
KUNLUN
MIRNY
DAVIS
CASEY
DUMONT D'URVILLE
DUMONT D'URVILLE SEA
DAVIS SEA
MAWSON SEA
MAWSON
SYOWA
MOLODEZHNAYA
MIZUHO
PRINCESS ELISABETH
DAKSHIN GANGOTRI
TROLL
MCMURDO
SCOTT BASE
MARIO ZUCCHELLI
GONDWANA
LENINGRADSKAYA
RUSSKAYA
ARTURO PARODI
ROTHERA
SAN MARTIN
PALMER
VERNADSKY
MELCHIOR
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GONZALEZ VIDELA
LUIS CARVAJAL
DRUZHNAYA 4
ENDERBY LAND
KEMP LAND
MAC.ROBERTSON LAND
PRINCESS ELIZABETH LAND
WILHELM II LAND
QUEEN MARY LAND
WILKES LAND
TERRE ADELIE
GEORGE V LAND
COATS LAND
DRONNING MAUD LAND
AMERY ICE SHELF
WEST ICE SHELF
SHACKLETON ICE SHELF
MCDONALD ISLANDS
HEARD ISLAND
Maximum Sea Ice Extent