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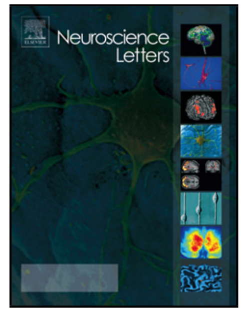

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Subjective Time Estimation in Antarctica: the impact of extreme environments and isolation on a time production task

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Highlights

- Short and Intermediate morning interval productions increased along the year.
- Intermediate evening interval productions increased during polar night.
- Morning performances might be influenced by emotional variations due to isolation.
- Evening performances might be modulated by circadian dysregulation.

Abstract

Interval timing measures time estimation in the seconds-to-minutes range. Antarctica provides a real-world context to study the effect of extreme photoperiods and isolation on time perception. The aim of this study was to explore interval timing as a cognitive measure in the crew of Belgrano II Argentine Antarctic Station. A total of 13 subjects were assessed for interval timing in short (3s), intermediate (6s) and long (12s) duration stimuli. Measures were taken during the morning and evening, five times along the year. Significant variations were found for 3s and 6s during the morning and 6s during the evening. Results suggest an impact of isolation on morning performances and an effect of the polar night on evening measures. These findings shed some light on the use of interval timing as a cognitive test to assess performance in extreme environments.

Interval timing - Antarctica - Polar night - Circadian Rhythms - Extreme environment

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Introduction

Time estimation is a major cognitive ability that allows humans and other animals to optimize behavioral functions. These activities require the skill to measure the elapsed time in several intervals [12], and involve multiple cognitive processes like attention, memory and decision making [47]. To assess this phenomenon, the most used procedure is interval timing [20, 25, 29, 43] which studies how a time interval is perceived, represented and estimated in a range of seconds to minutes [12].

Several studies have centered their attention on variables that can modulate time perception, such as emotion-related arousal [18, 49] and attention [46]. Other time scales of biological timing, like circadian or seasonal cycles, have also been proposed to influence interval timing [3, 21, 24]. Indeed, recent research have demonstrated the effects of the circadian clock on short-time estimation [1, 13]. Both the circadian oscillator and the sleep homeostat [11] appear to influence the rate at which the pacemaker emits pulses, evidenced in overproductions [48] .

The accuracy of timing performances can also be influenced by environmental variables [22]. In this respect, the extreme photoperiod of Antarctica, with up to four months of complete darkness (polar night) is an ideal experimental setting to determine the impact of different zeitgebers on circadian human rhythms. Influences of mood state and fatigue on time production task have also been reported [23]. Both variables, together with negative affect and hostility, constitute some of the prevalent psychological symptoms during polar expeditions [8, 38]. The impact of this context on cognitive processes is variable, with reports of no changes [19, 55], increases [9] or decreases in performance [39, 42].

Thus, circadian rhythms and emotional processes have a key relevance in the cognitive functions involved in time estimation. These factors are affected by extreme photoperiodicity, isolation and confinement conditions found in Antarctica. However, there is no evidence about how time estimation unfolds in this context. Therefore, the aim of this study was to assess interval timing in a crew overwintering in Antarctica. Our hypothesis is that polar night and isolation affect the cognitive processes required to estimate time during an overwintering mission in Antarctica. Accordingly, we expect to find less accurate performances and longer intervals due to the lack of natural light exposure and to emotional variations associated with prolonged isolation and confinement.

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Methods

Experimental setting

Belgrano II station is located at sea level on the mainland (Nunatak Bertrab; 77° 51'S and 34° 33'W), 1300 km away from the South Pole. Characterized by its extreme weather, the station is considered one of the coldest, driest and most isolated territories of the world, with temperatures that oscillate between -43 º C during winter and 5 º C during summer. Concerning its southern position, Belgrano II station has a distinctive light-dark cycle, with almost four months of polar night, with total darkness, and four months of day, with constant daylight conditions (Table 1). A working schedule of eight hours (9 am – 6 pm) is carried out, with fixed hours for breakfast, lunch and dinner.

Sample

Our sample was constituted by a military crew of 13 healthy men (range age 34 ± 1 years) with similar anthropometric characteristics, who volunteered to participate in the Antarctic campaign.

Interval timing

This is an observational, analytical and longitudinal study. Time estimation was assessed every other month (March, May, July, September, and November) during one year at Belgrano II Argentine Antarctic station. Due to working schedules constraints, subjects were distributed into groups of three or four to be measured during one week of the month. Measurements took place in the morning (between 9:00 and 11:00) and in the evening (between 20:00 and 22:00). All the participants completed the assessment within an hour. They were evaluated by using a time production task described in detail elsewhere [2]. Briefly, participants performed a visual task on a laptop. First, a blue square with the word "Observe" was presented on the screen as the target interval. After a 500-millisecond pause, a red square appeared with the word "Produce". Participants had to press the spacebar when they judged that the duration of the second square matched the blue one. Short (3s), intermediate (6s) and long (12s) intervals were evaluated in 24-trial blocks. The first four target intervals of each block were used as practice trials and they were not

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included in the analyses. Participants were instructed not to count or foot tap. Compliance with the task was monitored to ensure the validity of the obtained data. The entire evaluation lasted around ten minutes. Three variables were derived from interval timing performances: 1) “Response Time”, the mean estimated time for each session, which measures the mean duration of the time estimates; 2) “Coefficient of variation”, the ratio between the standard deviation of estimated times and “Response time”, which measures the relative time estimation dispersion, it refers to the reproducibility of a measurement, meaning that an increase in coefficient of variation shows lower repeatability of the data in relation to the mean Response time, independently of the target interval ; and 3) “Accuracy”, the percentage of hits achieved by the subjects, considering a faultless performance an interval estimated within ± 5 percent of the target interval, it refers to the closeness of the measurement to the target interval (3s, 6s, 12s), an increase in accuracy means better performances. We used "Time of day" to refer to the morning and evening sessions and we used "Time of year" to refer to the months where the measures were taken. We attributed "overproductions" to productions that were longer than the target interval and "underproductions" to productions that were shorter than the target interval.

A psychological screening, consisting of the Beck Depression Inventory-II and the Beck Anxiety Inventory, was also performed during each measurement point to rule out affective changes related to depression or anxiety. The scores were within normal values at the beginning of the campaign and showed non-significant variations throughout the year.

Statistical Analyses

Differences between Time of year (March, May, July, September, and November) and Time of day (measures taken during the morning and the evening) were assessed by two-way repeated measures ANOVA applied to each dependent variable within each of the three time interval levels. Sidak alpha-level correction for multiple comparison was applied to control the family wise error rate of separate paired samples *t*-test as a post-hoc procedure conducted for Time of year (with a critical p value of 0.0051) and for Time of day (with a critical p value of 0.0102). Finally, a Benjamini–Hochberg procedure was applied to correct for the use of separate two-way ANOVA testing.

Ethics

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This study was approved by the Ethics Committee from the National University of Quilmes (Argentina), and was conducted according to the Declaration of Helsinki. Subjects were properly informed about the aim and nature of this research and invited to participate. The participants prior to the study provided written informed consents.

Results

Figure 1 shows Response time, Coefficient of variation and Accuracy during the year, for morning and evening sessions and for 3s, 6s, and 12s timing intervals. For the shortest interval evaluated (3s), the interaction between Time of day and Time of year for Response time was significant during the campaign, showing different patterns between morning and evening productions ($p < 0.017$, Figure 1. A, Table 2). When analyzing the effect of Time of year within each Time of day, we observed that during the morning 3s intervals were estimated differently between the beginning and the end of the year. At the beginning of the expedition intervals were underestimated, while at the end of the expedition they were overestimated (Mar < Nov, $p < 0.001$; Sidak post hoc procedure). In contrast, during the evening, a tendency to overestimate productions was seen during the winter (Sidak post hoc procedure ns). Differences between morning and evening sessions were non-significant for all measurement points (Sidak correction for multiple testing, Figure 1. A, Table 2). Coefficient of variation showed no significant changes for any of the analyzed factors (Figure 1. B, Table 2). Accuracy during the evening was significantly greater than during the morning, while no significant variations were found throughout the year (Figure 1. C, Table 2). The interaction between Time of day and Time of year was non-significant (Figure 1. C, Table 2).

For the intermediate interval evaluated (6s), the interaction between Time of day and Time of year for Response time was significant during the campaign, showing different patterns between morning and evening productions ($p < 0.018$; Figure 1D, Table 2). Time estimated in the morning increased along the year with significant differences between months (Mar < Nov, $p < 0.001$; Sidak post hoc procedure). Although measures taken during the evening showed non-significant variations, they evidenced a noticeable tendency to exhibit greater values during winter (Sidak post hoc procedure ns). Namely, these differences varied significantly during the year, evidencing a similar pattern to the short interval productions: while in March, during the morning, participants tended to

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underestimate the target intervals, in November they overestimated them. In contrast, during the evening intervals were overestimated in winter. Coefficient of variation for the 6s-interval exhibited a significant interaction between Time of day and Time of year (Figure 1. E, Table 2 interaction $p < 0.014$) with non significant post hoc variations (Sidak post hoc procedure ns). The analysis of Time of day effect within each Time of year indicated significant differences for May ($p < 0.001$; Sidak correction for multiple testing). Accuracy showed no significant differences for any the analyzed factors (Figure 1. F, Table 2).

Finally, for the longest interval evaluated (12s), Response time, Coefficient of variation and Accuracy displayed non-significant differences for any of the analyzed factors (Figure 1. G, H, I, Table 2)

Discussion

This study represents the first evidence for interval timing performed in Antarctica. Its main result is the progressive increment of mean Response time for 3s (short) and 6s (intermediate) intervals estimated during the morning, in contrast with the Response time for intermediate levels estimated during the evening which increased only during winter. This evidence supports our hypothesis showing that isolation and seasonality seem to modulate the cognitive ability to estimate time. Both factors appear to influence differentially morning and evening productions. Our predictions related to a lengthening effect were reinforced, while accuracy assumptions were not evidenced.

The relationship between cognitive performance and extreme environmental conditions has been described before [27, 28]. Particularly, evaluating time estimation during an overwintering in Antarctica involves the interaction of a wide range of variables that can shape this phenomenon, such as extreme weather [10], isolated and confined conditions [34], exposure to radiation [57], and mental health [35]. We assume that subjective time perception was not a result of multiple repetitions of the task during the year, since other studies have evidenced that time estimation, assayed through a 30s-production task in a non-polar region, showed virtually no changes in control subjects along a one-year period [53]. Despite the lack of longitudinal studies in which shorter intervals were examined we consider that a possible practice effect may be discounted, since performance (as reflected by accuracy) did not improve throughout the campaign. Considering the extremely cold climate that characterizes this environment, it could be thought that temperature influenced the participant´s performances. Indeed, increasing body

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temperature results in shorter time reproductions [54]. However, in this study, tasks were performed indoor with constant temperature conditions maintained by central heating.

Regarding the seasonality modulation that we had expected, increases in the evening 6s group-mean Response time up to July (winter) and the reduction in Response time thereafter may be interpreted as the effect of chronobiological variables. As we have described previously, July is characterized by its complete darkness, while March and November present almost constant daylight, so our findings showed a similar pattern to that of natural light exposure. Interval length appears to be modulated by the photoperiod evidenced in lower values at the beginning of the expedition, an increase in the intervals during polar night and a decline in the length at the end of the isolation period. This is also supported by the Coefficient of variation results for the 6s evening data. Changes in photoperiodicity during Antarctic expeditions result in circadian desynchrony as seen in sleep onset phase delay and sleep disruptions [6, 19]. It is also known that time estimation is modulated by the circadian clock [1, 13], which, in turn, is synchronized by light [26, 44]. Furthermore, it has been demonstrated that exposure to bright light accelerates the internal pacemaker [30]. Thus, the absence of natural light during winter, typical from Antarctica [7], might affect circadian rhythms resulting in slower pulses and longer intervals productions during the evening as we predicted. Previous studies have revealed that the light-dark cycle appeared not to be essential for diurnal variations in time perception [45]. Accuracy evidenced better performances during the night compared to the morning, as it has been previously found [32], but without the seasonal variations that we had hypothesized. Although practice trials were given prior each task, familiarity with the procedure could facilitate evening performances [50].

On the other hand, increases in mean Response time for short and medium intervals during the morning along one year of confinement may be explained by changes in the subject´s mood state due to isolation conditions. A seasonality effect may be discounted as results did not correlate with seasonal changes in lighting conditions. As we have hypothesized, the isolation context, which usually promotes lack of motivation, boredom, impaired interpersonal relationships, and emotional variations, might have an impact on subjective time estimation by slowing down the pulses within the timing clock and therefore producing longer intervals. Although our screening confirmed the psychological well-being of the participants, these subjects lived through a long period in a confined place with limited activities, configuring an ideal scenario for emotional instability [38]. In addition, psychological changes during Antarctic expeditions have been well described [15, 35, 52],

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showing that extreme environments, as well as mood fluctuations, impact negatively on performance [5, 40]. Furthermore, boredom correlates with poorer performances in remote contexts [36] and motivational aspects play a main role in Antarctica experiences and its potentially detrimental effects [33]. Isolation and confined conditions also influence social support, leading to a greater number of psychological symptoms [34]. A reduction in the speed of the flow of time in depressed patients has already been reported [51], as well as a diurnal increase of negative affect followed by a decline over the course of the day [41], which may explain variations found only during the morning. Our results are consistent with those that show increases in fatigue during the second semester of the year in similar conditions [37]. Considering the mechanisms underlining the clock rate misalignment, decreases in dopaminergic activity have been associated with overestimated intervals [16, 56]. We have hypothesized that isolation conditions may be of great importance for interval productions as it is widely recognized that emotional experiences can alter time perception [4, 25]. During emotionally arousing experiences [25] an underestimation of temporal duration was reported, which results in a lengthening effect on time intervals [17]. More stable emotional patterns also influence time production tasks, exhibiting an effect of mood, fatigue, and irritability on time perception [23]. Interestingly, 12-sec interval timing did not change along the day nor throughout the year, evidencing different pacemaker rates through several interval durations [48].

In summary, our data suggest that interval timing can be influenced by seasonal variations associated with the lack of exposure to natural light as well as by psychological variables associated with the extreme isolation and confinement conditions of Antarctica. Alertness has been measured during the same campaign showing non-significant variations [19], evidencing that time production task might be a more sensitive tool to evaluate the impact of extreme environments on cognitive processes. Further studies of time perception should include the measure of other cognitive functions as assessed by multidomain batteries like the neuropsychological battery of the "Consortium to Establish a Registry for Alzheimer's Disease" (CERAD), which measures language functions, verbal learning, visuospatial functions, delayed recall, memory consolidation, recognition memory, and executive functions [31]. It also remains to be studied how cognitive and circadian measurements act as cofactors in the observed results. Although these findings should be tested with bigger samples and compared with a control group, they offer a clue to uncover the nature of these processes and point out the possibility of using time estimation tasks as screening tools for the early detection of mood changes, fatigue or performance decays [14].

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Contributors

C.T. and P.A. study conception and design, data collection, data analysis and interpretation, drafting the manuscript; A.F. data collection; M.B. study conception; J.M.C. study design; M.C. data collection; D.A.G. study conception and data interpretation; S.A.P. and D.E.V. study conception and design, data analysis and interpretation, drafting of the manuscript. All authors reviewed the manuscript and approved the final version.

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Research Data

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Figure 1

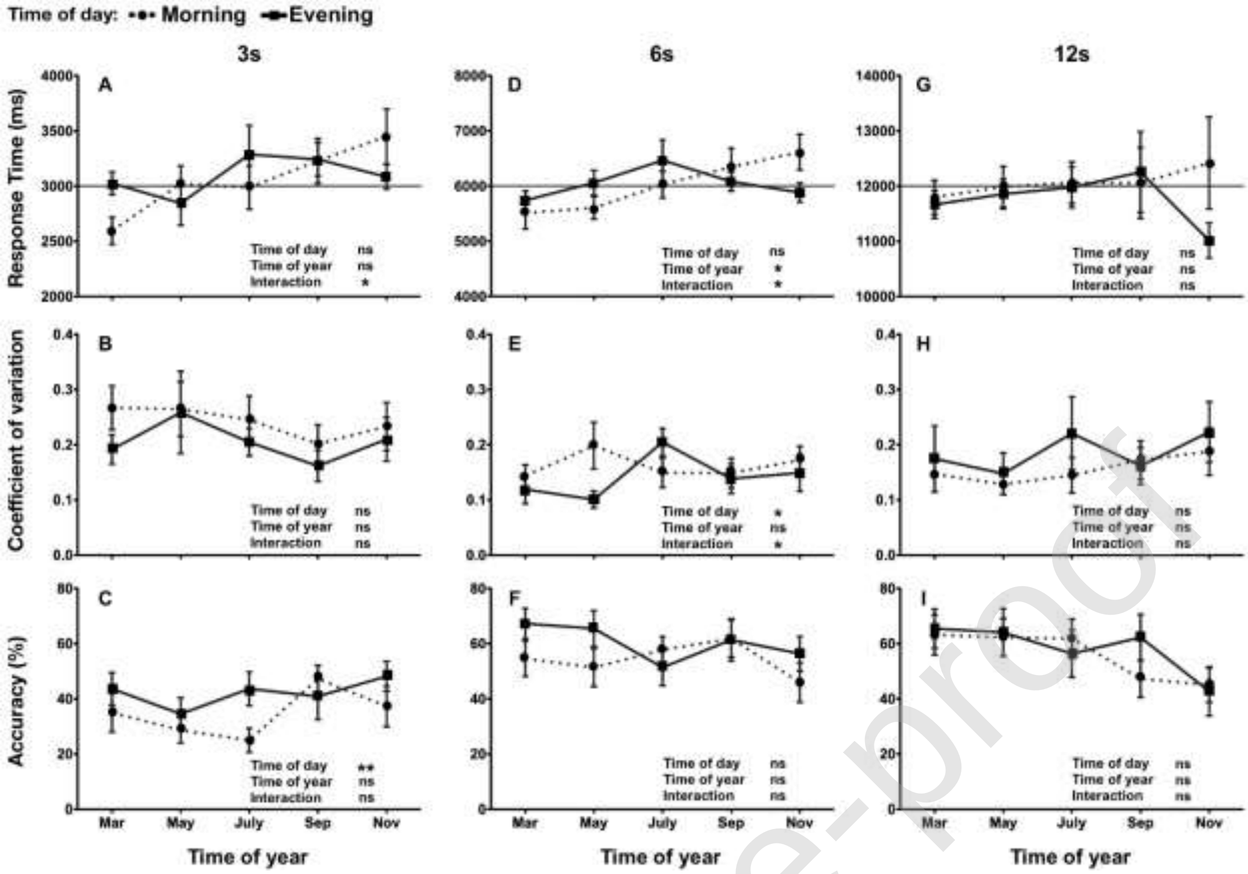

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Table 1. Natural sunlight conditions in Belgrano II station

	Sunrise	Sunset	Natural sunlight (h per day)
March	04:31	18:19	17.5
May	Down all day		0
July	Down all day		0
Sept	05:54	16:36	14
Nov	Up all day		24

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Table 2. Repeated measures two-way Anova analyses of Time of year and Time of day for Response time, Variation coefficient and Accuracy for each interval.

		3s		6s		12s	
		F (dfn, dfd)	p	F (dfn, dfd)	p	F (dfn, dfd)	p
Response time	Time of year	2.868 (4, 48)	0.095	4.173 (4, 48)	0.017	0.576 (4, 44)	0.968
	Time of day	0.321 (1, 12)	0.927	0.062 (1, 12)	0.993	2.177 (1, 11)	0.424
	Interaction	4.106 (4, 48)	0.018	4.139 (4, 48)	0.017	0.612 (4, 44)	0.959
Coefficient of variation	Time of year	1.699 (4, 48)	0.419	1.407 (4 ,48)	0.572	1.541 (4, 48)	0.498
	Time of day	2.100 (1, 12)	0.434	9.501 (1, 12)	0.028	1.264 (1, 12)	0.631
	Interaction	0.330 (4, 48)	0.997	4.326 (4, 48)	0.014	1.255 (4, 48)	0.658
Accuracy	Time of year	1.636 (4, 44)	0.453	1.020 (4, 44)	0.792	1.456 (4, 48)	0.544
	Time of day	15.08 (1, 11)	0.008	5.898 (1, 11)	0.097	0.722 (1, 12)	0.797
	Interaction	1.136 (4, 44)	0.728	1.165 (4, 44)	0.712	1.603 (4, 48)	0.466

Legend: 3s (3-second interval), 6s (6-second interval), 12s (12-second interval), F (F-statistic), dfn (degree of freedom from between the columns), dfd (degree of freedom from within the columns).

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