

## Cognitive effects of long-term residence in the Antarctic environment

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**Abstract** This study examined whether prolonged residence in the Antarctica had a significant impact on cognitive performance. Participants were members of the 24th and 25th Chinese National Antarctic Research Expeditions. Cognitive performance was measured with tests designed to evaluate short-term recognition, memory search and spatial cognition, measured four times: January, March, April, and June 2010. Age was controlled as a covariate, and data were analyzed using repeated-measures ANOVA. The results revealed that subjects' short-term memory and recognition ability remained stable, while 82% of team members exhibited improved scores on a spatial cognitive ability test. These findings have important implications for furthering our understanding of cognitive functioning in extreme environments.

**Keywords** Antarctica, prolonged residence, cognitive performance, memory, spatial cognition

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### 0 Introduction

The Antarctic environment is characterized by a number of unique features: geographical remoteness, strong wind, heavy snow, and polar nights. Scientific research teams endure extreme temperatures and extended periods of confinement in a monotonous location. Solitude and the removal of familiar perceptual and cognitive environments present several potential cognitive challenges to team members, including response accuracy and processing speed, which are associated with short-term memory and spatial cognitive skills.

Several previous studies have suggested that prolonged exposure to extreme conditions, such as those found in the Antarctic, may cause impairments in cognitive functioning<sup>[1-3]</sup>. It has been reported that certain extreme

conditions such as frigid cold and prolonged isolation may negatively impact vigilance, concentration, memory, and reasoning ability<sup>[4]</sup>. White and colleagues argued that, compared to a control group, the winter-over team performed worse on cognitive tests<sup>[5]</sup>. However, some researchers have suggested that with increased time in the Antarctic, people actually exhibited improvements in certain areas aspects of cognitive performance<sup>[6-7]</sup>. For example, Defayolle et al.<sup>[8]</sup> reported that Antarctic expeditioners' cognitive performance improved on measures of transient memory, visual discrimination and reaction time. More recently John et al.<sup>[9]</sup> reported that during long-term Antarctic residence, explorers exhibited improved short-term recognition, delayed recognition, and digit symbol substitution scores, while their concentration level remained stable. These findings suggest that long periods of relative deprivation in the Antarctic may not negatively impact cognitive functioning, and might even lead to improvement in some aspects of cognition<sup>[10-11]</sup>.

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A small number of Chinese psychological studies have focused on changes in cognition in the polar environment, producing variable results. For example, Xue et al.<sup>[12]</sup> argued that personnel staying over winter at Great Wall Station of China demonstrated stable reaction times in discriminative and choice reaction tasks, delayed simple task reaction time, and improved memory scores. However, Yan et al.<sup>[13]</sup> surveyed 38 winter-over staff who had served at Great Wall and Zhongshan stations at least once between 1984 and 2002, finding that 42% of test subjects reported memory impairment during the mission, and 68% reported memory problems after they returned to China.

The conflicting results described above may be explained by the use of different tests to measure different aspects of cognitive ability, with some studies using simple tasks and others using complex tasks. Suedfeld<sup>[14]</sup> evaluated the complexity of different cognitive tests, suggesting that prolonged residence in the Antarctic was positively correlated with improvements in basic cognitive skills such as memory, vigilance, and simple learning in contrast to a negative correlation with more complex cognitive skills. Zhang and colleagues observed and evaluated the team members of the 6th Chinese National Antarctic Research Expedition (CHINARE) at Great Wall Station and the team members of the 8th CHINARE at the Zhongshan Station. They concluded that after 2 months in Antarctica, simple memory-related cognitive abilities remained stable, while complex memory decoding abilities declined; after 3–6 months in Antarctica, more complex abstract character coding abilities declined significantly; nevertheless, the easiest 3-digit addition skills remained stable<sup>[15-16]</sup>. However, Palinkas and colleagues reported that performance improved in three complex tasks but deteriorated in two simple tasks<sup>[10]</sup>.

As discussed above, several theories have been proposed to explain the change of cognitive performance in extreme environments, including sensory deprivation and task complexity. However, only a few studies have examined the relationship between the length of residence and the change in cognitive skills, and the findings are equivocal. Therefore, the present study tested the length of residence as an independent variable and changes in cognitive performance as a dependent variable, seeking to further explore the relationship between the length of residence and cognitive performance.

We employed computer-based tests to examine the cognitive performance of winter-over expeditioners in the 25th CHINARE at Great Wall Station. Memory is an important cognitive function, and forms the foundation of more complex cognitive activities. In this study, a short-term recognition task and a typical memory search task were used to examine memory. Recognition tasks are relatively simple, reflecting basic memory functionality. Memory search tasks, however, are more complex, requiring both recognition and search. Moreover, spatial cognition, a more complex cognitive skill, is also important for people working in extreme environments. Spatial cognition

involves not only spatial perception, but also concentration, search, mental rotation, and other advanced cognitive processes. We used a mental rotation task to assess changes in spatial cognition. Spatial cognition has not been examined in previous studies, adding another dimension to the impact of the Antarctic environment on cognitive functioning.

## 1 Method

### 1.1 Participants

A total of 26 participants (23 males and 3 females, including scientific, technical and construction personnel) of the 25th CHINARE from Great Wall Station of China (62°12'59"S, 58°57'52"E) volunteered to participate in this study. The mean age of participants was 35 a (Standard Deviation (SD) = 9.67 a). The Great Wall Station experiences a typical Antarctic marine climate. In January, the warmest month, the average temperature was 1.5°C and the highest temperature was 13°C. In August, the coldest month, the average temperature was -7.8°C and the lowest temperature was -28.5°C.

Five of 26 participants had served in the 24th CHINARE winter-over team for 12 months, and agreed to work with the 25th CHINARE in Antarctica for 3 additional months, referred to as the 'overwintered members' in this study. 21 newly arriving participants belonging to the 25th CHINARE were also assessed within one month of arriving at the Antarctic station referred as newly arrived in the study. However, two of these participants did not undergo the recognition and memory search tasks, and three did not undergo the spatial cognition task. Eleven members of the 25th wintering-over team stayed in the Antarctic for an entire summer—winter period, from December 2008 to December 2009. They participated in the longitudinal study.

After being informed of the objectives and data collection procedure of this study, all 26 participants agreed to take part in the research. The first author of this study worked as a psychologist in the expedition team and conducted an assessment in the first session. It should be noted that there was an internet connection at Great Wall Station, so all participants were able to freely communicate with the outside world. This changes the view of isolation in the context of extreme environmental conditions, and adds another unique dimension to the study.

### 1.2 Experimental design and procedure

Two short-term memory tests and one computer-based spatial cognition test were administered to participants as follows. 16 participants were assessed only once during the summer, in January 2009. The other 11 participants were assessed three times (January, April and June) to examine memory-related cognition and four times (January, March, April and June) to measure spatial ability. The accuracy rate (ACC) and reaction time (RT) for correct responses were measured as dependent variables. All three tests were conducted using E-prime software, and administered by the

first author of this study and the physician on Great Wall Station. A repeated-measures within-subjects design was employed in the three assessments.

**1.3 Materials**

As described above, the present study contained three tests, which were easy to administer and could be broadly viewed as measures of working memory and spatial cognitive ability. Character recognition and memory search were employed to measure memory-related cognition, and the mental rotation task was used to measure spatial cognition ability. To avoid the effects of practice, two parallel test materials were used alternately.

**1.3.1 Recognition task**

In the recognition test, 20 two-character Chinese words were first presented one by one; each word was displayed in the middle of the screen for 1 s, then a black screen was presented for 0.5 s. The subjects were instructed to memorize as many items as possible. Following an interference

presentation of 2 min, subjects were then presented with 40 characters and asked to identify the 20 characters that were previously displayed. The obtained accuracy score (ACC) is the number of correct responses to the 20 stimulus items.

**1.3.2 Memory search task**

The memory search task was used to assess short-term working memory and to gauge concentration level. In this test, a single character (number or capital letter) was first presented as a target for 2 s. A stimulus set consisting of 2 to 8 characters was then presented. The subject was asked to judge whether the stimulus set contained the target or not, by pressing key Y for “yes” or N for “no” on the keyboard. Each subject repeated this test 64 times. As shown in Table 1, the test was designed to balance two factors: the length of stimulus set and the location of the target stimulus. This measure comprises both ACC and RT measures, with the latter measure reflecting the time to respond following the presentation of the stimulus set.

**Table 1** The design of memory search experiment

	Length of stimuli (No. of characters)													
	2		4				6				8			
Position of target stimulus	1	2	1	2	3	4	3	4	5	6	2	4	6	8
Times of responses on each kind of stimulus	4						2							

**1.3.3 Mental rotation task**

A mental rotation task was used to assess spatial cognitive ability. Test materials included 80 custom-made image stimuli, displaying a vertical or horizontal line of five letters; 40 pictures contained the letter E and another 40 of them contained the letter H. The design was balanced among three factors: color (green or red), position of target letter (1-5), and direction (vertical or horizontal). Subjects were asked to identify whether the picture contained E or H by pressing the E or H keys on the keyboard. Each picture was displayed randomly three times. In total, 240 responses were collected. The ACC and RT of each response were recorded.

longer than those of the more recently arrived personnel in both memory search and mental rotation. We conducted an ANOVA while controlling for age as a covariate. The results revealed that ACC in the mental rotation task was significantly higher in the overwintered group than in the newly arrived group ( $F_{ACC\_rotation}(1,20) = 4.98, p_{ACC\_rotation} = 0.04 < 0.05$ ), whereas no significant difference was found between the two group in the RTs in the mental rotation task, or in other tasks ( $F(1,21)_{ACC\_recognition} = 1.12, p_{ACC\_recognition} = 0.30; F(1,21)_{RT\_recognition} = 0.86, p_{RT\_recognition} = 0.36; F(1,21)_{ACC\_search} = 0.32, p_{ACC\_search} = 0.57; F(1,21)_{RT\_search} = 1.32, p_{RT\_search} = 0.26; F(1,20)_{RT\_rotation} = 0.30, p_{RT\_rotation} = 0.59$ ).

**2 Results**

**2.1 Comparison of overwintered and newly arrived explorers**

As shown in Table 2, in the first test session in January we compared the mean score and SD of responses between the overwintered and the newly arrived subjects.

In the recognition task, ACC of overwintered explorers was lower than those of the newly arrived members, while RT was longer. The RTs of overwintered participants were

**2.2 Longitudinal study of cognitive performance from summer to mid-winter**

All 11 members of the wintering-over group participated in the longitudinal study. The mean scores and SDs of responses on tasks measured at three different phases of wintering are presented in Table 3.

The AAC of the recognition tasks exhibited a generally declining trend, while RTs fluctuated from summer to mid-winter. ACC gradually declined over the four times, during which the memory search task was administered, while the RTs in the mental rotation task became shorter. However, when age was controlled as a covariate, the re-

peated-measures ANOVA indicated that none of the changes were significant ( $F(2,12)_{ACC\_recognition}=0.01$ ,  $p_{ACC\_recognition}=0.99$ ;  $F(2,12)_{RT\_recognition}=0.40$ ,  $p_{RT\_recognition}=0.68$ ;  $F(3,18)_{ACC\_search}=2.62$ ,  $p_{ACC\_search}=0.08$ ;  $F(3,18)_{RT\_search}=0.60$ ,  $p_{RT\_search}=0.62$ ;  $F(3,18)_{ACC\_rotation}=0.26$ ,  $p_{ACC\_rotation}=0.85$ ;  $F(3,18)_{ACC\_rotation}=0.38$ ,  $p_{ACC\_rotation}=0.77$ ).

**Table 2** Comparison of the overwintered and newly arrived personnel

Task	Groups	N	ACC		RT	
			Mean	(SD)	Mean	(SD)
Recognition	Newly arrived	19	0.812	(0.060)	787.079	(101.571)
	Overwintered	5	0.775	(0.064)	885.900	(267.779)
Memory search	Newly arrived	19	0.947	(0.031)	775.079	(171.03)
	Overwintered	5	0.963	(0.034)	924.500	(153.20)
Spatial cognition	Newly- arrived	18	0.970	(0.023)	772.583	(101.918)
	Overwintered	5	0.994	(0.007)	817.900	(66.089)

Importantly, among 11 wintering-over explorers, 60% showed a decline in ACC in the three recognition tasks, while 60% exhibited shorter RTs in the same tests. Across the four memory search task sessions, ACC of 54% of the wintering-over explorers declined, while the RTs of 91% of subjects became shorter. Across the four mental rotation tasks, the ACC of 72% of the subjects increased, and the

RTs of 82% of the subjects became shorter.

The data presented above indicate that after prolonged residency in the Antarctic, Chinese polar explorers' performance in short-term recognition and memory search tasks remained stable, while spatial cognition significantly improved.

**Table 3** Accuracy and reaction time of responses in three experiments during a wintering-over expedition in Antarctica

		Jan	Mar	Apr	Jun
Recognition	ACC(SD)	0.838(0.076)	—	0.866(0.086)	0.831(0.087)
	RT(SD)	807.750(100.189)	—	733.188(73.278)	815.375(216.457)
Memory search	ACC(SD)	0.961(0.031)	0.959(0.012)	0.953(0.022)	0.951(0.033)
	RT(SD)	813.375(209.631)	764.438(181.346)	699.438(142.143)	730.00(156.420)
Spatial cognition	ACC(SD)	0.972(0.016)	0.975(0.018)	0.972(0.020)	0.974(0.025)
	RT(SD)	779.563(127.555)	755.938(86.074)	734.813(79.900)	751.250(138.384)

### 3 Discussion

The purpose of this research was to further examine the effects of extreme environments on specific cognitive functions. In particular, we examined memory, attention and information processing among CHINARE who spent part of the year (summer only) or who stayed for a full year, including the winter period, in the Antarctic. When controlling for age as a covariate, the results suggested that the summer only and the wintered-over staff exhibited no statistically significant differences in either of the memory measures. Our longitudinal study of the wintering-over team members also showed that, from summer to mid-winter, short-term recognition memory and memory search ability exhibited a small and statistically non-significant decline. These results indicated that basic memory functioning was not significantly affected by a prolonged period spent in the climatically extreme and iso-

lated Antarctic environment. These findings are consistent with those, for example, of John et al.<sup>[9]</sup>, and Xue et al.<sup>[12]</sup>. Previous studies of memory employed different types of cognitive measurement, including transient memory tasks<sup>[8]</sup>, short-term recognition tasks<sup>[11]</sup>, and short-term memory tasks<sup>[15]</sup>. Taken together with previous findings, the current results support the notion that the Antarctic winter experience does not negatively impact on basic cognitive functioning and performance. In contrast, some cognitive scores appeared to improve slightly, although this improvement may be due to artifacts of small sample size or measurement error.

Importantly, the memory test score findings reported here conflict with self-reports from Antarctic team members obtained after they completed their expeditions. In a previous study by Yan and Tang<sup>[13]</sup>, Chinese Antarctic explorers reported that they believed they had experienced memory deterioration, including difficulty memorizing task details

and recognizing familiar objects. Zhang et al.<sup>[16]</sup> reported that memory coding abilities showed some decline after 3 to 6 months in Antarctica. There are two possible interpretations for these inconsistent findings. First, stimulus deprivation may have influenced the results. People working in Antarctica before 2005 faced a much more isolated and confined environment than the participants in the current study. Information from outside the station was rare and extremely limited before 2005, especially during the long winter. For example, the most precious source of outside information for previous stationers was calling home, which they were able to do for less than 5 min per month. This proposed explanation should be tested by further investigation. Second, the inconsistent result could be attributed to the specific tasks used in the study, which call for a different level of information processing. The transient and short-term memory tasks employed in present study can be classified in the easy-mid level of difficulty. In contrast, the subjective reports from explorers mainly concerned long-term memory, which is more difficult, and the memory coding tasks employed in Zhang's study also required more complex cognitive skills. Suedfeld<sup>[14]</sup> had earlier offered an explanation that might shed light on this varying memory data obtained from the Antarctic scientific teams. These findings suggest that performance on easy-to mid-level memory tasks remains stable or may even improve over time, whereas more complex and challenging memory tasks may show some decline with time.

The spatial ability test revealed that the accuracy rates of overwintered explorers were significantly higher than those of the summer-over residents. The results showed that 72% of the overwintered explorers exhibited improvements in spatial cognitive performance and 82% of the overwintered explorers exhibited shorter RTs. Thus mental rotation scores reflecting spatial ability were not impaired by time spent in the Antarctic environment and in fact showed a small improvement. This is important to note, because spatial cognition is important for survival in extreme environments, so it is encouraging that the present findings suggest that this ability does not decline within the time frame of the study. However, as Suedfeld suggested, because of the complexity of the tasks, researchers should be cautious when examining spatial cognitive abilities in extreme environments without first examining simple, medium and more difficult and complex variants of spatial reasoning ability. More comprehensive and ecologically relevant research should be conducted before firm conclusions are drawn.

Taking the results of the memory and spatial cognition tasks together, the current findings support the view that, at least within a year of time spent in Antarctica, basic cognitive skills such as short-term memory recognition, memory search, and spatial cognition are not negatively or adversely impacted. Rather, spatial cognition even tended to show some improvement with time. However, several confounding factors may have influenced these results, and the extreme conditions attributed to Antarctic expeditions appear to have substantially changed over time. Accommodation

and equipment for outside work have improved so that extreme climatic conditions are less critical than they were in the past. Regarding social isolation, internet access, including Skype, has become available during the research period. Chinese Antarctic explorers are now able to communicate with their families, friends and the "outside world", acquiring instant and current information. Thus, the availability of the Internet has changed the cognitive and social environment previously experienced in remote and harsh environments, and now provides explorers with access to aspects of their external lives that are relevant and important. These changes may be key in preventing the deterioration of cognitive abilities and other psychological factors. Second, this research is limited in several ways (e.g., the specific tests used, the limited range of cognitive variables, etc.), particularly the length of this study, which only lasted six months from summer to mid-winter. The findings and tentative conclusions presented in this study require further confirmation, as do the other research studies cited in this paper, since their data on cognitive changes in the polar environment also spanned less than one year.

As explorations of extreme environments such as deep sea, outer space, and Antarctica continue, it is obvious that explorers will be required to reside or work in those environments for much longer periods of time, in some cases years and even decades. Thus, future research should include prolonged longitudinal studies. Finally, it should be noted that the changes we observed, including the deterioration and improvement of basic cognitive abilities, arise from certain physiological bases. In test results from 101 Chinese Antarctic explorers' between 1986 and 1996, Xue et al.<sup>[17]</sup> found that the secretion of the adrenal cortex, three hormones from the medulla region, and male hormone increased. This increase lasted for approximately one year, and was sometimes found even after the explorers returned home. Incidentally, the four measured hormones are known to facilitate concentration and thus promote cognitive functioning. Thus, future research on human responses to extreme environments should also consider the interface between physical and psychological factors.

#### 4 Conclusion

The present study assessed the cognitive performance of team members of the 25th CHINARE (2009) at Great Wall Station, and found that, from summer to mid-winter:

(1) Short-term recognition and memory search ability scores were stable.

(2) 82% of winter-over explorers exhibited some improvement in mental rotation performance.

(3) Shorter periods of time (less than a year with or without wintering over) spent in the Antarctic scientific research station did not have a negative impact on the cognitive functions assessed in this study.

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