Original Article

Temporal adjustments in working memory and vigilance function during 6 days of acclimatisation at 10,500 feet altitude

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ABSTRACT

Operational exigencies sometimes do not permit aviators to acclimatize adequately for 6 days as recommended at an operating altitude of 10,500 feet. This study was conducted to examine the adequacy of a short acclimatization (of 36 hours) in terms of certain cognitive attributes viz., working memory and vigilance functions. A cross section of 197 subjects was examined during the period of acclimatisation for 6 days after induction by air. Out of these, 20 subjects were also followed longitudinally. To factor out effects of familiarity and practice, 20 'controls' were examined at the ground level for a similar duration. All the subjects were low landers. In the cross sectional group of subjects, performance in both working memory and vigilance tasks did not vary across the period of acclimatisation. Response accuracy and reaction time were essentially comparable after 36 hours and 6 days of induction ($p>0.05$; Kruskal-Wallis ANOVA). In the subjects followed longitudinally, a consistent improvement was noticeable from 2nd or 3rd day onwards ($p<0.05$; Friedman ANOVA). However, this improvement was comparable to that observed in the 'controls' ($p>0.05$; Wilcoxon Matched Pairs Test). Approximately 8-10% of the subjects exhibited Acute Mountain Score (AMS) Scores>4 on Lake Louise protocol between 2nd to 4th day after induction. However, we did not find any correlation between AMS Scores and performance in the above tasks ($p>0.05$; Spearman Rank Order Correlation). The study notices comparable performance in working memory and vigilance tasks after 36 hours and 6 days of induction to 10,500 feet.

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Army aviators operating in high altitude areas follow a short acclimatisation schedule of 36 hours after induction to base altitude of approximately 10,500 feet. Even though without much physiologic justification, the short acclimatisation schedule has been prescribed due to considerations of operational exigencies. Ironically, this is the period during which most acclimatisation mechanisms are known to have evolved only inadequately. The effect of exposure to such moderate altitudes on cognitive attributes is a controversial issue [1,2,3,4,5]. To complicate the matter further, an improvement in cognitive functions is reported during acclimatisation [6,7]. However, most of these studies suffer from a multitude of methodological inadequacies e.g., too small a sample size to permit any worthwhile statistical analysis, effects of familiarity with the evaluation procedure, an isolated approach in the evaluation and finally, use of climbers who are known to suffer from mild yet persistent cognitive

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impairment. Due to these reasons, validity of certain studies conducted to examine the temporal adjustments in these attributes during acclimatisation is questionable.

The present study was conducted to examine whether a longer acclimatisation of 6 days results into a better adjustment in certain cognitive attributes viz., working memory and vigilance compared to short acclimatisation of 24-36 hours being followed by Army aviators.

Material and Methods

Experiment Design

Experiment design included both longitudinal and cross sectional evaluation of subjects over a period of six days following induction to an altitude of 10,500 feet. Additionally, a group of 'controls' was also evaluated for a comparable duration at ground level at Bangalore. The control group was set up to factor out the confounding effects of repeated task administration on performance in the longitudinal experiment design at high altitude.

In the study, 197 subjects were evaluated. Number of subjects evaluated on separate days is given in Table 1. These groups were designated as 'Cross Sectional Groups'.

Out of 39 subjects evaluated on Day-1 in the 'Cross Sectional' study, 20 were also followed longitudinally for 6 days. This group is hereafter referred to as 'Longitudinal Group'.

'Control Group' comprised of 20 subjects evaluated longitudinally for 6 days at ground level. Physical attributes of the subjects in all these 8 Groups (Cross Sectional-6, Longitudinal-1and Control-1) were comparable statistically (Table 1).

Subjects

All subjects were healthy male volunteers who refrained from smoking at least two hours prior to study. On Day-1, subjects were evaluated within 6 hours of arrival to high altitude. On subsequent days, experimentation was conducted between 1000-1300 hours. For 152 subjects, it was the first exposure to high altitude. Out of these, 103 were fresh inductees. Others had

Table 1: Subjects physical attributes

		Age (yr)	Height (cm)	Weight (kg)
Longitudinal (n=40)	At High Altitude (n=20)	31±6	170±5	67±11
	Controls (n=20)	29±6	167±6	63±7
Cross Sectional (n=197)	Day1 (n=39)	31±6	171±6	65±7
	Day2 (n=38)	33±6	168±4	62±8
	Day3 (n=32)	33±6	170±5	64±6
	Day4 (n=23)	30±6	169±4	63±7
	Day5 (n=37)	30±6	171±6	63±6
	Day6 (n=28)	32±6	170±6	64±7

Physical attributes are not different across the Groups
p=0.199, 0.083 and 0.385 for age, height and weight, respectively (Uni-variate ANOVA)

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already spent an average of 15 months at high altitudes and had come back having spent an average of 47 days at lower altitudes. The subjects were essentially low landers. The induction in all the cases was by air.

Experimentation

Experimentation involved administration of PC-based working memory and vigilance tasks. In the working memory task, subject was to identify a target stimulus in an array of similar stimuli. The stimulus was one of 90 geometrical figures of different shapes and of the size of approximately 3.8 x 2.5 cm. The array comprised of 4 such stimuli (two on the left and the other two on the right of the array) arranged horizontally with an inter-stimulus separation of 0.6 cm. One of these stimuli might be (or might not be) the target stimulus. The subject was asked to respond, by different key presses, if the target appeared in the right or the left of the array or it did not appear in the array at all. All these occurrences were kept equi-probable in the task programme. There were two unique features of the task; first, the subject had to wait till the disappearance of both target and array before executing a response (otherwise the response was not accepted by the programme) and secondly, the next target appeared only when the subject had responded. Characteristics of the task were as given below in Table 2.

Table 2: Characteristics of the task

	Values in ms
Pre-target delay	700
Exposure time of target	800
Pre-array delay	700
Exposure time of array	800
Inter-stimulus delay	100

Number of correct and incorrect responses, total number of stimuli presented and response time for the instances wherein the target appeared in the right or left of the array or when the target did not appear in the array were computed automatically by the programme and displayed at the end of the task. The task was administered for about 5 minutes. However, to account for the minor variations, correct responses were standardised for a total of 75 attempts. Therefore, correct responses presented in results below are correct responses x 75 / number of attempts.

In the vigilance task, subject was to recognise a consecutively repeated appearance of any target and respond by a single key press. The target stimuli were from a group of 90 geometrical figures of different shapes and of the size of 3.8 x 2.5 cm. Exposure time of target (stimulus) was 200 ms and inter-stimulus delay was 3000 ms. Number of correct and incorrect responses, total number of stimuli presented and response time were computed automatically by the programme and displayed at the end of the task. Correct responses were standardised for 100 targets.

Task familiarisation

In view of a separate group of 'Controls' which was set up to factor the effects of repeated task administration, subjects were not allowed to 'practice' the tasks. They were only made familiar with the procedure.

Scoring of Acute Mountain Sickness (AMS) with Lake Louise Protocol

Details of the procedure are available elsewhere [8]. A score of 5 or above was considered as occurrence of (significant) Acute Mountain Sickness [8]. Lake Louise protocol is nowadays preferred over the Environmental Survey Questionnaire (ESQ) [9] and is almost universally accepted.

Statistical Analysis

Data are presented as mean ±SD. Physical attributes of subjects in the 8 groups were compared using uni-variate ANOVA. Performance data, AMS (Lake Louise) scores across the period of study (i.e. 6 days) in the Longitudinal Study Group were analysed using Friedman ANOVA which is a non parametric equivalent of ANOVA with repeated measures. Subsequent to a positive outcome, individual comparisons were made with the help of Wilcoxon Matched Pairs test. McNemar χ^2 statistic, as applicable to such dependent samples, was used to analyse occurrence of significant AMS (defined as number of individuals with AMS Score of 5 or more).

Evaluation of controls was essentially a longitudinal design and similar statistical methods (except McNemar χ^2 statistic) were applied.

Corresponding analyses in the Cross Sectional Groups were made using Kruskal Wallis ANOVA, Mann Whitney test and χ^2 analysis.

To compare the extent of improvement in the performance due to repeated task administration between the Longitudinal Group and Controls, Mann Whitney test was applied.

The above stated non parametric procedures were resorted to due to significant departures of data from normality examined with a Shapiro Wilk's W statistic.

Evaluation of relationship between AMS Score and performance was made using Spearman's Rank Order Correlation Coefficient.

Results

AMS (Lake Louise) Scores of the subjects in the Longitudinal and Cross Sectional Groups are given in Table 2. Scores were significantly higher on Days 2 to 5 in both the groups. However, the number of subjects with a score of 5 or more was found not to be significantly different on 2nd,

Table 2: Lake Louise Scores

Longitudinal group

	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	p
Scores	0	2±2	2±2	2±1	1±1	1±1	0.000 *
Subjects with Score >4	0	2** [10%]	2** [10%]	0	0	0	

* Friedman ANOVA. Individual comparisons using Wilcoxon Matched Pairs Test showed that scores remain significantly higher on D2 to D5 [p<0.01]

** Not different from D1; p=0.157 (McNemar χ^2 Test)

Cross Sectional group

	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	p
Scores	0.0±1	2±2	2±2	2±1	1±1	1±1	0.000 *
Subjects with Score >4	3** [3%]	1** [8%]	1** [3%]	0 [4%]	0		

* Kruskal-Wallis ANOVA. Individual comparisons using Mann Whitney Test showed that scores remain significantly higher on D2 to D5 [p<0.01]

** Not different from D1; p=0.292, 0.887, 0.147 for D2, D3, D4, respectively (χ^2 Test)

3rd and 4th days. Performance (response time and accuracy) data of the subjects in the working memory and vigilance tasks are presented in Fig1 and 2 respectively. In the Longitudinal Group significant improvement was noticeable from 2nd to 3rd day onwards. A comparable extent of improvement was noticeable in the 'Controls' who were evaluated longitudinally for six days on ground level. No significant variation in the performance was seen across the period in the Cross Sectional Group.

Correlation between AMS Score and performance was poor. Values of Spearman's Rank Order Correlation Coefficient were 0.069 ($p=0.359$) and 0.069 ($p=0.359$) for the correct responses and reaction time respectively in the working memory task. Corresponding values in the vigilance task were 0.044 ($p=0.542$) and 0.066 ($p=0.358$).

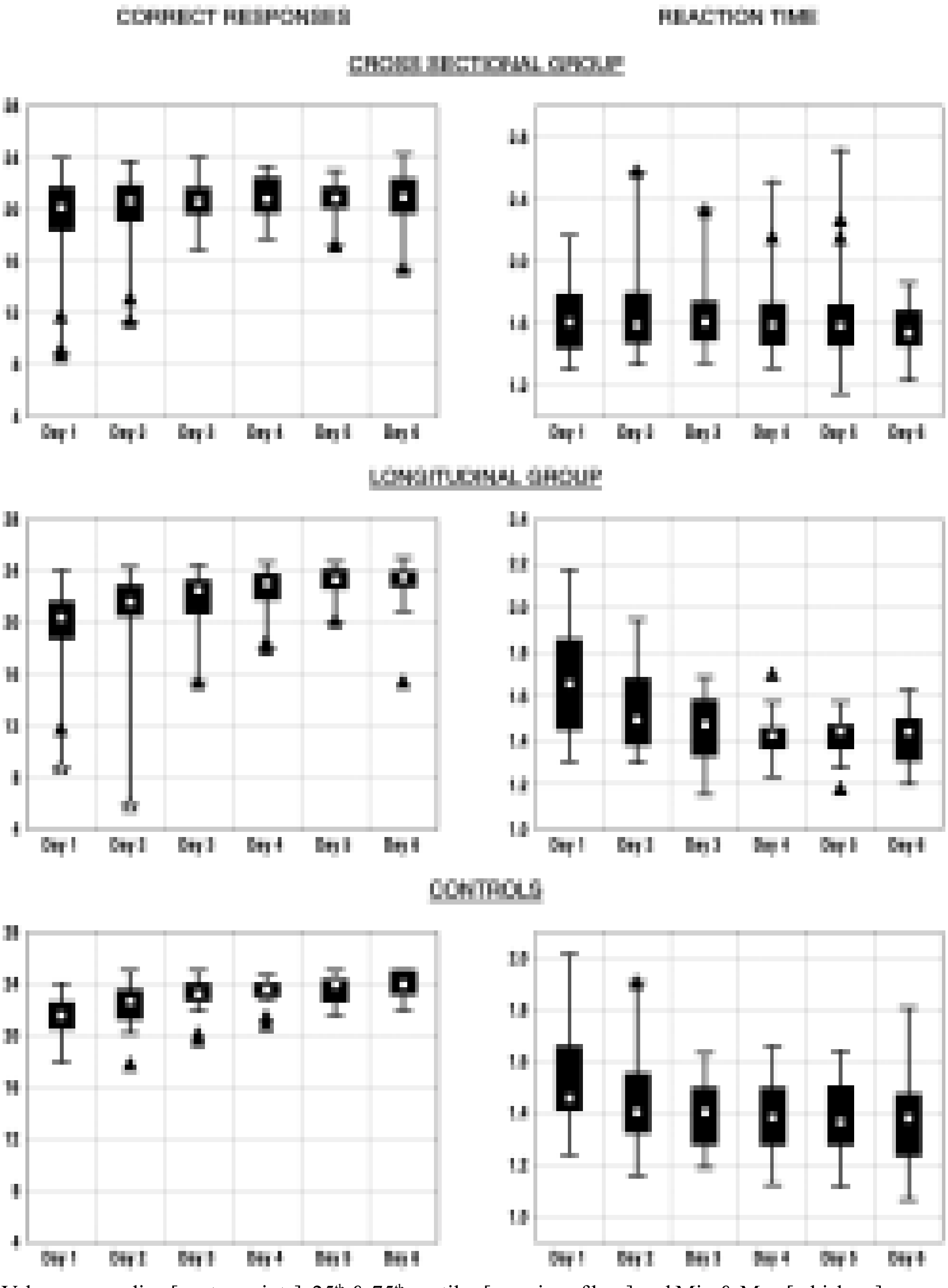
Discussion

In the present study, performance in working memory and vigilance tasks and AMS (Lake Louise) Scores were evaluated across a period of 6 days following induction to an altitude of 10,500 feet. Experiment design was carefully chosen to factor the effect of repeated task administration. Even though AMS Scores were significantly higher on Days 2 to 5 in both the group, the occurrence of AMS was low (8-10%) and the number of subjects with a score of 5 or more was found not to be significantly different on 2nd, 3rd and 4th days. It is in consonance with the reported prevalence of AMS at these elevations [8].

Improvement in the task performance (as evident from response time and accuracy) of the subjects in the Longitudinal Group was essentially due to familiarity and not as a result of acclimatisation. This inference is lent support from a comparable extent of improvement noticeable in the 'Controls' who were evaluated longitudinally for six days on ground level and an absence of a significant variation in the performance across the period of acclimatisation in the Cross Sectional Group.

The study, therefore, failed to establish any variation in the working memory and vigilance functions across the period of acclimatisation at 10,500 feet. The above findings seem to be surprising in view of certain studies wherein an impairment in working memory functions is reported at comparable altitudes. Bakharev [6] reported that performance in a variety of memory tasks was considerably worse during the first day at 3,400-3,600 m, the average decrement was 10-20% and, in some cases, even 30%. Similarly, Pagani et al. [7] noted an improvement in performance with acclimatisation. However, the latter study was conducted at a higher altitude of 5350 m.

This variation is intelligible in view of the wide divergence in the findings of the studies which have attempted to measure cognitive functions at these moderate altitudes. Denison et al. [1] have reported a decrement in performance at simulated altitudes as low at 5,000 and 8,000 feet. Later, it was attributed to physical exertion involved in the execution of their tasks. Similarly, Kramer [5] observed that relative to a matched control group that performed the tasks at sea level, the climbers showed deficits in learning and retention in perceptual and memory tasks. The participants were tested during a mountain climb (Mount Denali, Alaska) at 3,028 feet, at 14,301 feet after their attempt at the summit (which is at 20,316 feet) and again at 3,028 feet. Furthermore, climbers performed more slowly on most of the tasks than



1. Values are median [centre points], 25th & 75th centiles [margins of box] and Min & Max [whiskers]
2. No significant variation was seen in the Cross Sectional Group across 6 days [Kruskal-Wallis ANOVA]
3. Significant improvement was noticeable in both Longitudinal Group and Controls [Friedman's ANOVA]
4. Extent of above improvement in the performance in the Longitudinal Group (at high altitude) & Controls (at ground level) was comparable [Mann Whitney Test].

Fig 1: Perfomance in working memory task

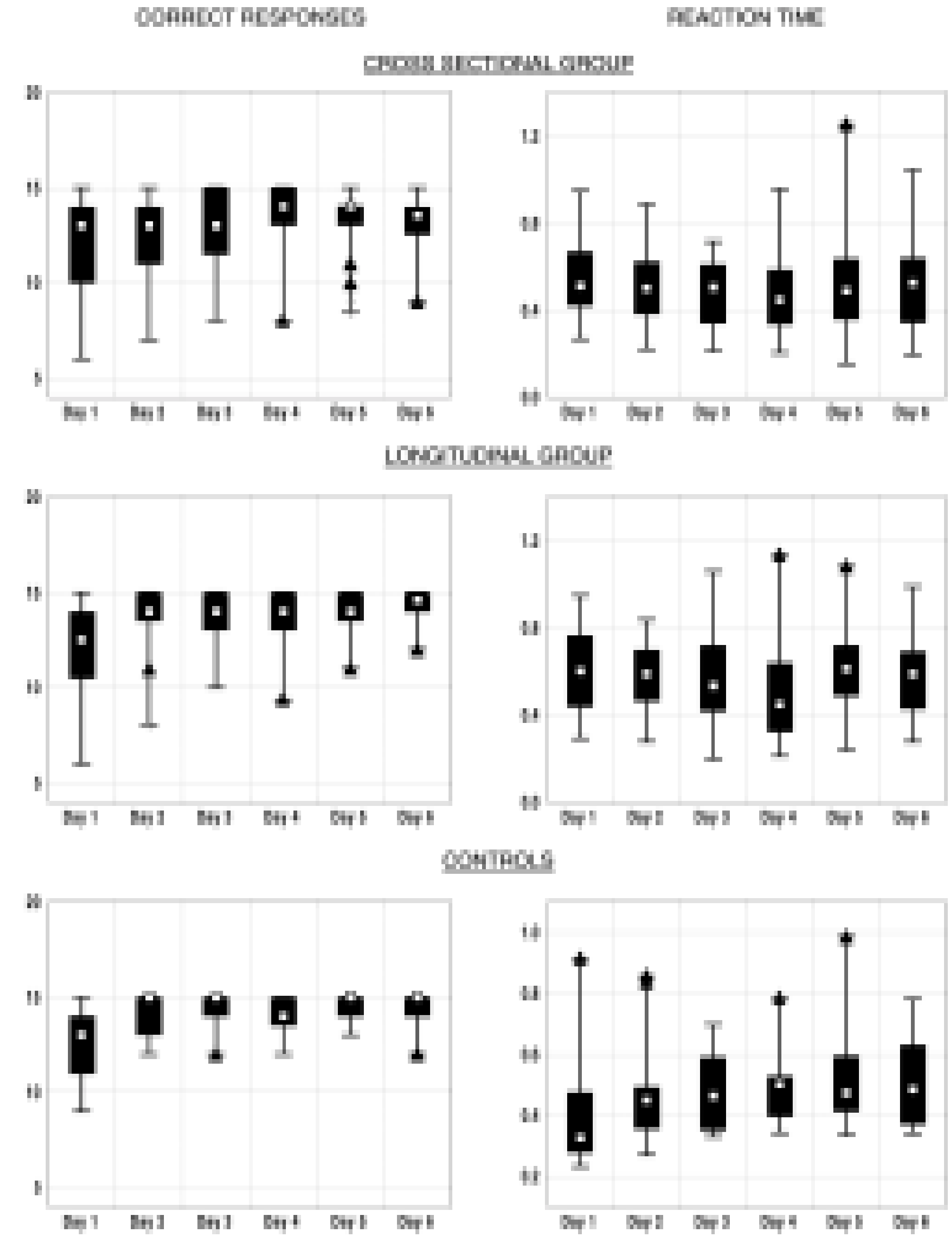


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Fig 2: Perfomance in vigilance task

did the control group. Contrary to above, Fiorica et al. [2] did not observe any degradation in simple vigilance performance in a group even after 4 hours of exposure to 11,500 feet.

Fowler et al. [3] re-examined the issue to find the minimum altitude which could affect the performance. In the first experiment no slowing of reaction time to a spatial transformation task was found at a simulated altitude of 8,000 feet. However, in their second experiment, reaction time did show an increase. In yet another study, Fowler et al. [4] using hypoxic gas mixtures modulated the haemoglobin saturation in 2% steps (between 86-76%) and identified a minimum equivalent altitude of 9,750 feet for the degradation of performance.

Nevertheless, more recent studies have failed to identify such a decrement in cognitive abilities at comparable (or even higher) elevation. Bartholomew [10] studied the effects of moderate altitudes (12,500 feet and 15,000 feet) on short term memory in simulation (in comparison to that at 2,000 feet). Participants performed a 30 minute vigilance task while listening to an audio tape with instructions to recall radio calls prefaced by their assigned call sign. Half of the radio calls were high memory loads (at least 4 pieces of information) and half were low memory load (no more than 2 pieces of information). No effects of altitude were found in performance on the vigilance task. However, for read-backs of high memory load, significant deficits in recall were observed at 12,500 feet and 15,000 feet. No effect of altitude was observed on recall of read-backs with low memory load. Similar results are available from studies which have been conducted at even higher altitudes. In 'EVEREST–COMEX 97' study, wherein eight subjects participated in a simulated climb from sea level to 8,848 m over a 31-day period of confinement in a decompression chamber, comparable learning effects and improvements in performance in psychomotor ability and number ordination is reported to occur at sea level and up to an altitude of 5,000-6,500 m [11].

Outcome of subsequent studies conducted by Fowler and his associates [12,13] has shown that an impairment in visual and auditory reaction time task or in perceptual motor performance occurs only at haemoglobin saturation below 81%. Haemoglobin desaturation of such an extent is unlikely in a healthy individual even after acute exposures to moderate altitudes as used in the present study (i.e., 10,500 feet). Additionally, short term memory storage and retrieval are shown not to be directly affected by hypoxia. It has been proposed that either direct or indirect slowing of the central executive of working memory may account for the cognitive deficits produced by this stressor [14]. Such an effect may not be apparent at mild altitudes as 10,000 feet.

Results from the present study show that the performance in both the tasks was found to be essentially comparable after 36 hours and 6 days following induction to this altitude. Thus, the study does not endorse inadequacy of the shorter acclimatisation schedule in terms of these attributes. Nevertheless, this refers only to working memory and vigilance functions and should not be extrapolated to other issues such as inadequacy in the physical work capacity, coagulation abnormalities, ventilatory and cold acclimatisation and compromised survival potentials.

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