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Performance During Mild Acute Hypoxia

M. A. PAUL, M.Sc., and W. D. FRASER, M.Sc.

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The controversy regarding the effects of mild hypoxia on learning performance needs to be resolved, since this may be affecting flight operations and safety. This study examined the ability to learn new tasks at low altitudes. Naive subjects (n = 144) performed spatial orientation (Manikin), serial choice reaction time (SCRT) and logical reasoning (Baddeley) tasks at ground level and at altitudes of 1,524 m (5,000 ft), 2,438 m (8,000 ft), 3,048 m (10,000 ft), and 3,658 m (12,000 ft), at rest or during exercise ($\dot{V}o_2$ = 600 ml $O_2 \cdot min^{-1}$) in a hypobaric chamber. Each task was performed over four serial repetitions (blocks) and presented at ground level or one of the four test altitudes in a first session, and in the reverse order in a second session. Performance for the Manikin and SCRT tasks improved significantly ($p < 0.0001$) over the 4 blocks. No significant difference was found between the corresponding 4 blocks of the first session in resting and exercising subjects tested at ground level before altitude compared to altitude before ground level. In general, RT for the 3 tasks were faster in resting than in exercising subjects. These results indicate that the ability to learn new tasks is not impaired by mild hypoxia at altitudes of up to 3,658 m. We detected a biphasic response to altitude in LRT and SCRT performance, but not for Manikin performance.

THE MINIMUM ALTITUDE at which perceptual-motor performance is compromised remains a controversial issue that has important implications for flight safety. Ernsting proposed that cabin pressure should be maintained at an altitude equivalent to 1,525 m (5,000 ft) for both military and civil aircraft operations, rather than the previously accepted 2,440 m (8,000 ft) (6). These conclusions are based primarily on evidence indicating that performance of complex unlearned tasks is impaired at altitudes of 2,440 m (3,5,10,13) and even as low as 1,525 m (5). The most influential work showing an effect of hypoxia on performance is that of Denison et al. (5) who reported a gradual recovery of the initial decrement in the capacity of naive subjects to learn a spatial orientation (Manikin) Task during mild exercise at low altitude. They concluded that the ability to respond to a novel task, but not to a well-learned task, was affected by mild hypoxia. However, these findings were not confirmed in a number of other studies designed to assess the effect of hypoxia on behavioral processes such as short-term memory (4), selective attention (13), logical reasoning (18), and spatial orientation (7; Paul, MA. Unpublished dissertation).

The discrepancies regarding the effects of mild hypoxia on perceptual-motor performance could be due to several factors. The main ones are as follows: the range of performance tests used may give rise to the possibility that different tests have different sensitivities to hypoxia; the way hypoxia is induced (hypobaric or low oxygen mixtures at ground level) may not result in equivalence in hypoxia; the physical workload of the test subjects while their performance is being assessed could have an effect on the ultimate severity of hypoxia.

Norris (19) found that the energy expenditure of a pilot during active instrument flight (holding patterns, instrument landing approaches, etc.) in a Canberra bomber was approximately 160 kg-m/min (27 W). In an effort to replicate cockpit workload, Denison et al. had their subjects pedal a cycle ergometer during their spatial orientation task. In an earlier study (7) carried out in this laboratory, hypoxic gas mixtures, the Manikin Task, and a secondary 27-W cycle ergometer task (to simulate normal cockpit workload with a corresponding $\dot{V}o_2$ of 600 ml $O_2 \cdot min^{-1}$) were used in an effort to replicate the results of Denison et al. (5). During this experiment it was noted that any subject could be made hypoxic to criterion Sao_2 of 88% to 90% (equivalent altitude of 8,000 ft to 10,000 ft) when seated quietly on the ergometer, but once cycling was initiated Sao_2 tended to fall. In order to maintain criterion Sao_2, it was necessary to switch to oxygen mixtures equivalent to lower altitudes.

Further analysis of this phenomenon was undertaken by assessing six subjects as follows. Pre-exercise saturation was controlled in quiet resting hypoxia at a criterion of 88–90%. This was followed by pedalling the

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From the Defence and Civil Institute of Environmental Medicine, North York, Ont., Canada.

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Address reprint requests to M. A. Paul, DCIEM, 1133 Sheppard Ave., North York, Ont., Canada M3M 3B9.

ergometer exactly as before but without attempting to control saturation by switching to oxygen mixtures equivalent to lower altitudes. After 15 min, the subject stopped pedalling while saturation was monitored for another 10 min. The results of this study indicated an average pedalling-induced drop in Sao_2 from 89% to 81.5%. This latter value corresponds to an altitude of approximately 3,600 to 4,000 m (12,000 to 13,000 ft). These results suggest that the subjects in the Denison et al. experiment were at a higher effective altitude than 2,438 m (8,000 ft) and/or that the effect of altitude on learning was due to uncontrolled variations in Sao_2 during exercise.

The purpose of this study was to determine if the ability of naive subjects to learn new tasks was affected by exposure to a range of mild acute hypoxic exposures in an altitude chamber, and to assess whether or not light exercise (27 w) modifies Sao_2 and performance at these altitudes.

METHODS

Subjects: The subjects used for the experiments were 144 young (19–25 years of age) volunteers from the Canadian Forces awaiting trade training. All participants were naive to the performance tasks and provided written informed consent. None had any previous experience with decompression to altitude in a hypobaric chamber. The protocol was approved by the DCIEM Human Ethics Committee.

Performance tasks: Spatial orientation (SOT) (5,11), logical reasoning (LRT) (1), and serial choice reaction time (SCRT) (12) tasks were performed at altitudes of 1,525 m (5,000 ft), 2,440 m (8,000 ft), 3,050 m (10,000 ft), and 3,660 m (12,000 ft). The tasks were also performed at ground level (GL) for control purposes. During all tasks, whether exercising or resting, subjects were seated on the bicycle ergometer. A stand was used to support the test materials and apparatus for both the LRT and SCRT tasks. This stand was constructed such that its upper surface could be rolled into place just above the handlebars of the cycle ergometer in a manner that did not render difficult either cycling or performance of the tasks. All subjects were instructed to perform each of the tasks as quickly as possible without errors.

SOT task: The SOT consisted of the same Manikin test used by Denison et al. (5) and illustrated in Fig. 1 of their paper. This task was originally designed by Benson and Gedye (11) to assess the ability of pilots to orient themselves with respect to an external visual reference system. Briefly, warning and problem slides were presented on an opaque screen by means of a projector (Kodak, model AF-3) which had its lens fitted with a tachistoscopic shutter (Lafayette, model 43011-16). The warning slide showed a central blue or orange disc. The colored disc disappeared after 2 s and was replaced 1 s later by a problem slide depicting the figure of a manikin in one of four orientations: upright or upside-down, and front or back facing. The manikin held a blue paddle in one hand and an orange one in the other hand. The problem slide was displayed for 5 s before the appearance of the next warning slide. In order to solve each problem, the subject had to decide in which hand (left or right) the manikin held the paddle whose color matched that of the disc on the warning slide, and then respond by depressing the corresponding button (Microswitch, model L103) mounted on the handlebars of the bicycle ergometer with his own right or left thumb. Thus, there were 16 possible combinations: 4 orientations × 2 responses (left or right) × 2 colors (orange or blue). A Digital Equipment Corporation PDP 11/04 computer was used to control the tachistoscopic shutter and slide projector, as well as for collection of the reaction time (RT) data. RT was defined as the time elapsed from the opening of the tachistoscopic shutter and the depression of one of the micro-switches. All 16 possible combinations made up one block. Each subject performed four blocks of this task over each session with each iteration given in a new random order.

LRT task: This pencil and paper test was described by Baddeley (1) as involving higher mental processes and based on grammatical transformation. This test consists of short sentences followed by a pair of letters (either AB or BA). The sentences claim to describe the order of the two letters. Subjects were to read each sentence and decide whether it was a true or false description of the associated letter pair. If the sentence described the letter pair correctly, the subject was to enter a tick in the first column (the true column) while if the sentence did not give a true description of the letter order, the subject was to put a tick in the second column (the false column). There were 32 possible combinations of the sentence and letter pairs. The test had all 32 possible combinations on each of 16 different test pages, each in a different random order. Each subject was randomly assigned four of these pages for each of two sessions; one session at ground level and one at his assigned test altitude. Each page represented one block of the four blocks performed during each session, with 30 s between blocks. The dependent measure was the total number of correct responses.

SCRT task: This five choice SCRT consisted of a

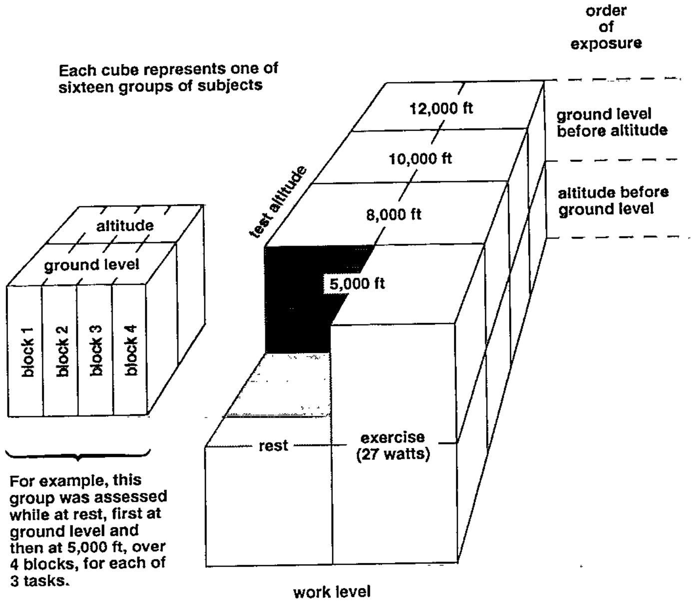

Fig. 1. Illustration of experimental design.

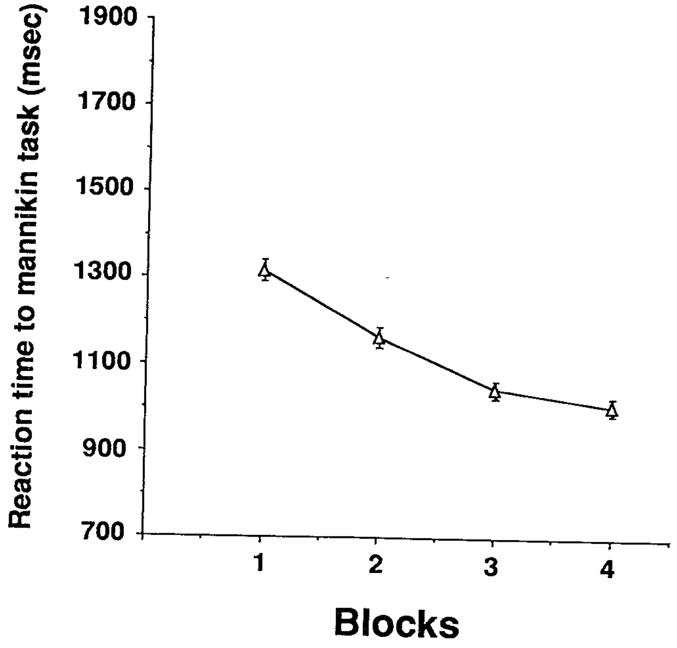

Fig. 2. Plot of reaction time (ms) to Manikin Task against blocks.

small module (61 cm × 61 cm × 10.6 cm) mounted on the stand (described above) such that the surface of the module was in a horizontal plane. The module was painted flat black and contained five push-buttons (Microswitch, model PK85022) with their heads projecting 1.5 cm above the surface. A 2-cm disc of unpainted aluminum was cemented to the head of each pushbutton. The buttons were arranged in the shape of a pentagon of which the adjacent points were 20 cm apart. A red light emitting diode (LED, Fairchild, model FLV560) was mounted outside the perimeter of the pentagon, adjacent to, and 2.18 cm from the edge of the push-button on a line from the center of the module projected through the center of each button. A PDP 11/04 computer was used to control a sequence of events in which an LED was illuminated until its adjacent disc was depressed. This simultaneously turned off the LED and randomly illuminated another one. The computer recorded the time interval between onset of illumination of each LED and depression of the corresponding button. The subjects used a 30-cm long wooden wand with 1.5-cm wide flat rubber tip to depress the buttons. This task was also performed in blocks. Here, a block was defined as the number of responses in 1 min. In any session, a subject performed for 4 blocks with 30 s between blocks.

Experimental Design and Procedure

Details of the experimental design are illustrated in Fig. 1. The subjects were randomly assigned to 16 groups divided equally among the four test altitudes (1,525 m, 2,440 m, 3,050 m, and 3,660 m). Of the four groups allocated to each altitude, two were tested at exercise and the other two were at rest. Of the two exercising groups, one was assessed at altitude before being tested at ground level. Similarly, of the two resting groups each group was tested in opposite order of exposure with respect to the altitude and ground level conditions. The subject performed all three tasks in both the altitude and the ground level sessions. Each task was presented in four blocks (repetitive trials of each task) and the order of presentation of the tasks was counterbalanced within and between groups in order to distribute any fatigue and time under hypoxia effects equally over the three tasks.

Subjects were decompressed singly, at a rate of approximately 1,500 m • min^{-1} for all altitude runs, as well as all ground level runs. For the ground level runs, once 1,525 m was reached, the chamber altitude was recompressed to ground level as slowly and imperceptibly as possible. This technique resulted in an effective single-blind procedure (each day at the end of testing subjects were asked to guess in which session they were exposed to altitude and most were unable to do so). Whether exercising or resting, subjects were allowed to remain at test altitude for 5 min before commencement of testing in order to permit equilibration of blood and alveolar gas tensions. The testing for each session lasted approximately 30 min with at least 1 h between sessions.

Physiological Monitoring

A Chemetron Medspec II mass spectrometer (model 7402) was connected via a 4-ft long heated cannula with a luer-lock fitting to an open-ended mouthpiece (Collins, 1⅜-in. diameter inlet) worn by the subject. The end of the cannula was within 1 cm. of the subject's lips. This arrangement allowed monitoring of respiratory frequency (f), as well as breath by breath analysis of end-tidal Po_2 and Pco_2 values. Arterial oxyhemoglobin saturation (Sao_2) was monitored with an ear oximeter (Hewlett Packard, Waltham, MA, model 47201A). All parameters were recorded continuously on a 4 channel FM tape recorder (Hewlett Packard, model 3960A) and displayed on a 3-channel strip chart recorder (Gould, Cleveland, OH, model 2107-4390-00).

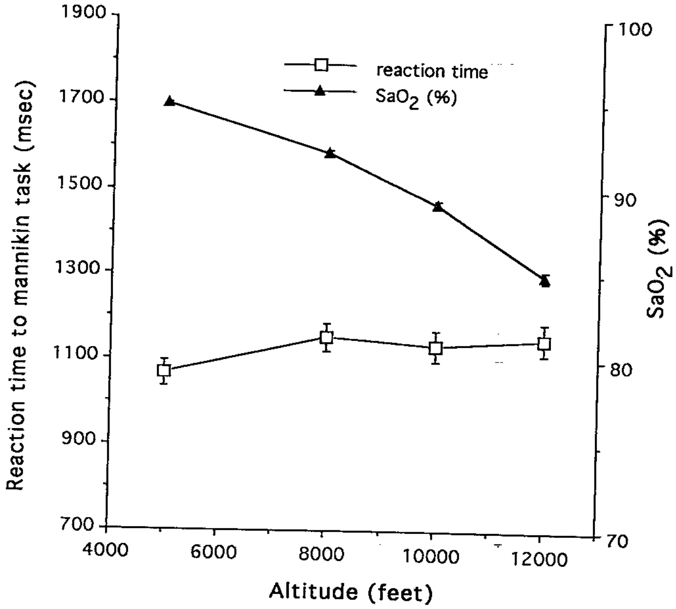

Fig. 3. Plot of manikin RT (ms) and arterial oxygen saturation (%) against altitude.

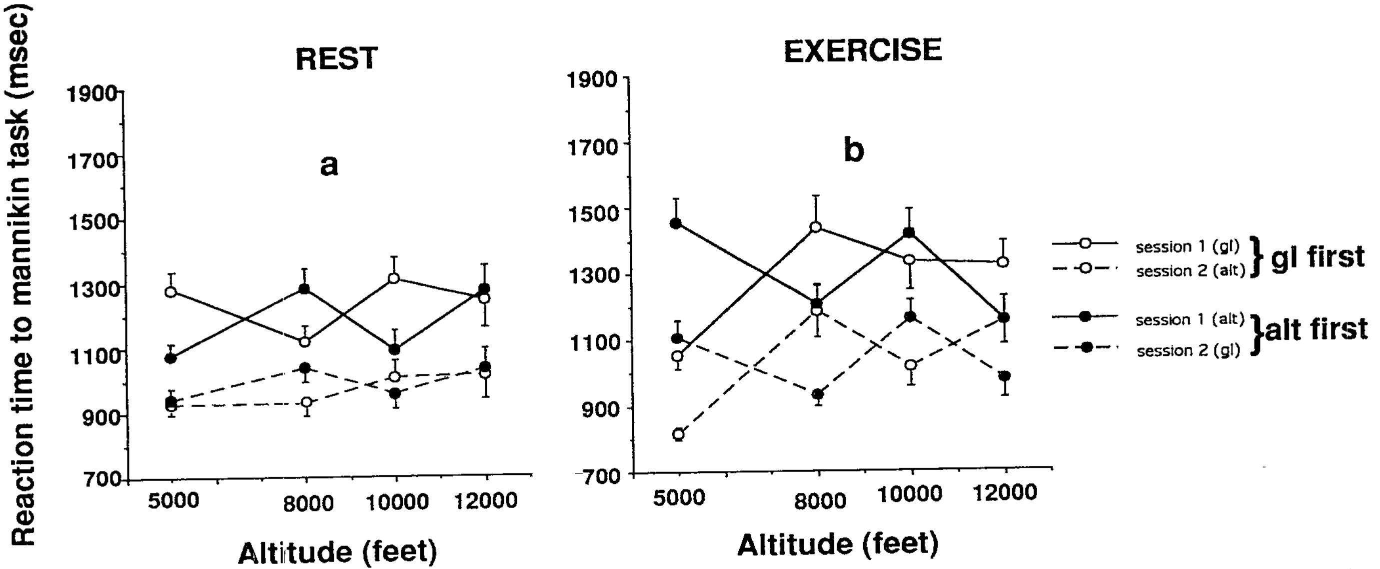

Fig. 4. Plot of manikin RT (ms) against altitude for resting (a) and exercising (b) subjects. Open circles represent ground level before altitude order of exposure; solid circles represent altitude before ground level order of exposure. Solid lines correspond to session 1; dashed lines correspond to session 2.

Statistical Analysis

In this study we examined the effects of altitude, which is a continuous independent variable, as well as the effects of blocks, exercise state, and the order in which the subjects performed their ground level control condition, and their altitude condition. Since there is a mix of categorical and continuous independent variables, the appropriate statistical approach is an analysis of covariance (ANCOVA) (10,20). In addition, blocks and gas are repeated measures. The dependent measures of all three performance tasks were submitted to a 3-factor (exercise, order of presentation, repeated blocks) by 1-regressor (altitude nested in repeated gas) ANCOVA. Here "gas" represents the breathing medium and has two levels: "ground level" and "hypoxia." Given that the level of altitude or "hypoxia" was different for each quartile of our subjects, altitude must be nested in gas in the general linear model used for the analysis (10). The Abacus Concepts, Super ANOVA software package (Abacus Concepts Inc., Berkeley, CA) was used to perform the statistical analysis. Each of the four physiological parameters was averaged (collapsed) over blocks and also submitted to a 3-factor (exercise, order of presentation, and tasks) by 1-regressor (altitude), ANCOVA with altitude again nested in gas.

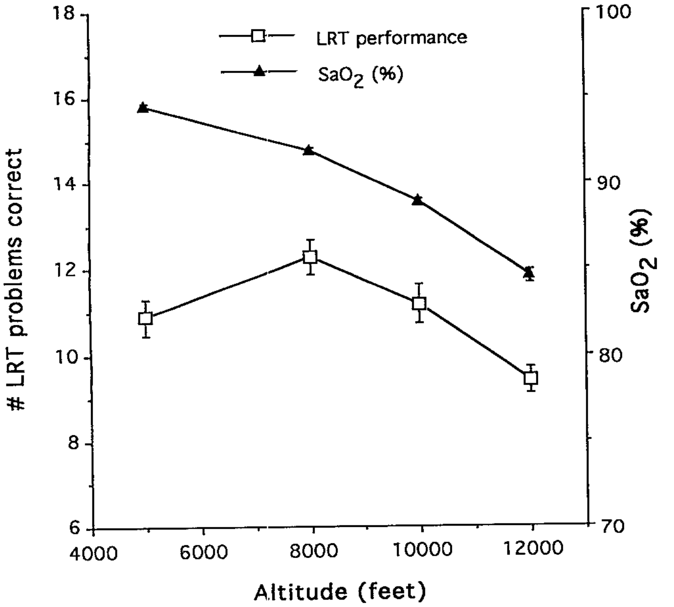

Fig. 5. Plot of # of LRT problems correct and arterial oxygen saturation (%) against altitude.

RESULTS

SOT Performance

There were main effects due to blocks ($p < 0.0001$) (Fig. 2), altitude ($p < 0.0496$) (Fig. 3), and exercise ($p < 0.0004$), where resting subjects performed faster (1,095 ms ± 15) than exercising subjects (1,171 ± 18). There was also an interaction between exercise, order of presentation, and altitude ($p < 0.006$) (Fig. 4).

The main effect of blocks (Fig. 2) indicates continuous learning of the Manikin Task while the main effect of altitude (Fig. 3) indicates a slight increase in reaction time to the Manikin Task with increasing altitude. Arterial oxygen saturation levels show the expected decrease with increasing altitude (Fig. 3). The variability between groups, as indicated by the ground level data for session 1 at both exercise and rest (Fig. 4), is greater than the effects of altitude. Subjects performed better during their second sessions whether at ground level or altitude.

LRT Performance

The main effect of blocks during the LRT task was not significant. The main effect of exercise indicates that resting subjects solved 11.3 ± 0.2 problems while their exercising counterparts solved 10.6 ± 0.2 ($p < 0.0052$). The quadratic main effect of altitude ($p <$

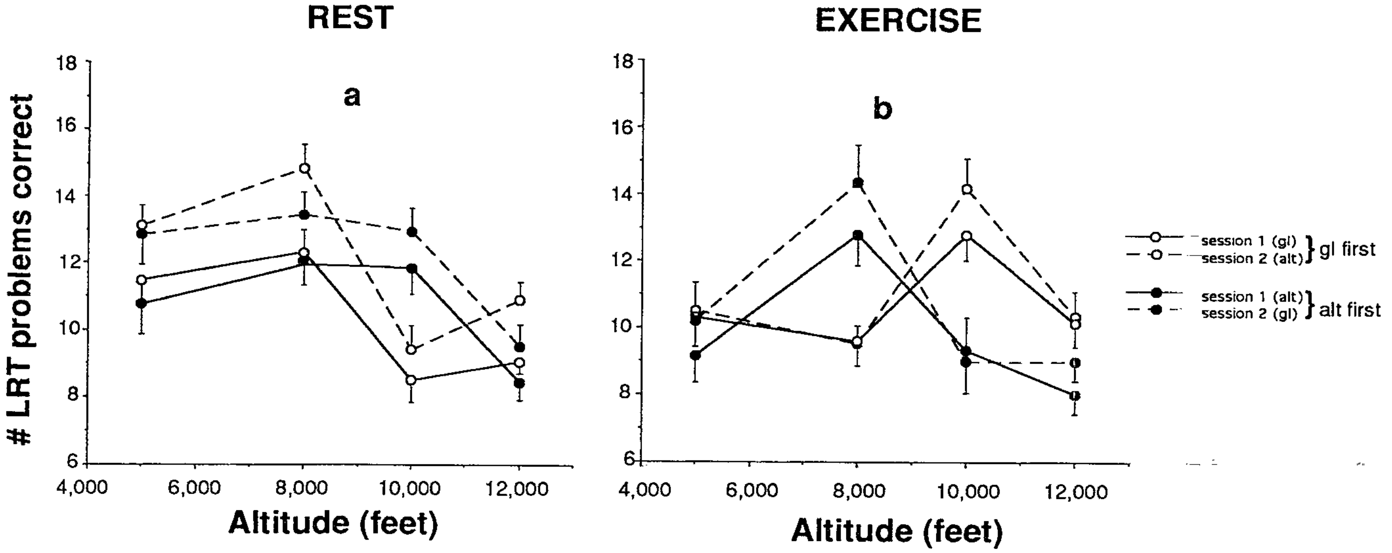

Fig. 6. Plot of # LRT problems correct against altitude for resting (a) and exercising (b) subjects. Legend as in Fig. 4.

0.0001) (Fig. 5) reveals performance to be better at 8,000 ft than at 5,000 ft, 10,000 ft, or 12,000 ft. The significant interaction between exercise, order of presentation, and altitude ($p < 0.0098$) is plotted in Fig. 6.

SCRT Performance

The significant main effect due to blocks ($p < 0.0001$) is plotted in Fig. 7 and indicates continuous learning of the SCRT task. The main effect of exercise reveals an SCRT performance of 548 ± 2 ms for resting subjects and 546 ± 2 ms for the exercising subjects ($p < 0.0001$). The main effect of order of presentation resulted in a reaction time of 544 ± 2 ms for ground level first subjects and 550 ± 2 ms for altitude first subjects ($p < 0.0441$). The main effect of altitude ($p < 0.0481$) is a significant quadratic function (Fig. 8). There was an interaction between exercise and altitude ($p < 0.0126$) (Fig. 9) as well as between order of presentation and altitude ($p < 0.0014$) (Fig. 10), and between exercise, order of presentation, and altitude ($p < 0.0497$) (Fig. 11).

Physiologic Parameters

There was a significant main effect of exercise for all four physiologic parameters (Sa_{O_2} ($p < 0.0008$), P_{O_2} ($p < 0.0036$), respiratory frequency (f) ($p < 0.0001$), and P_{CO_2} ($p < 0.0001$)). There was also a significant main effect of tasks on P_{O_2} ($p < 0.0036$), f ($p < 0.0001$), and P_{CO_2} ($p < 0.0189$), but not on Sa_{O_2}. The significant main effect of altitude on P_{CO_2} ($p < 0.0001$) was linear but was quadratic on Sa_{O_2} ($p < 0.0001$), P_{O_2} ($p < 0.0006$) and f ($p < 0.0199$). The significant interaction between exercise and altitude was quadratic for Sa_{O_2} ($p < 0.0066$) as well as for P_{O_2} ($p < .0034$) (Fig. 12).

DISCUSSION

The purpose of this study was to determine whether the ability of naive subjects to learn new tasks was af-

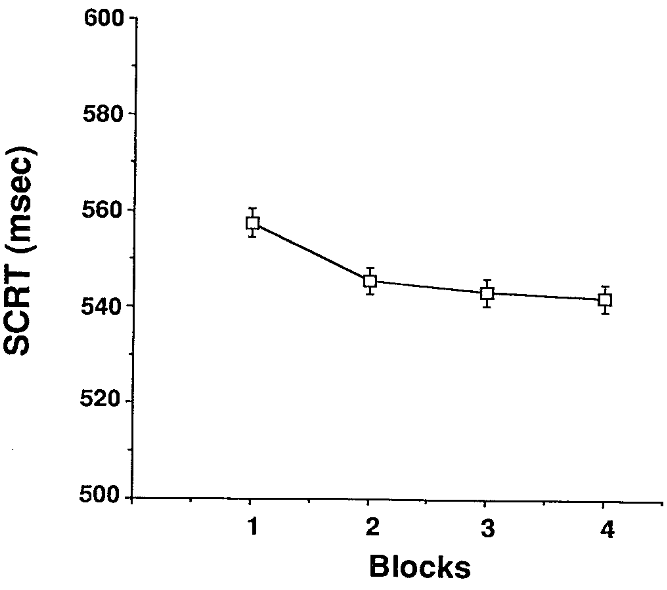

Fig. 7. Plot of SCRT (ms) against blocks.

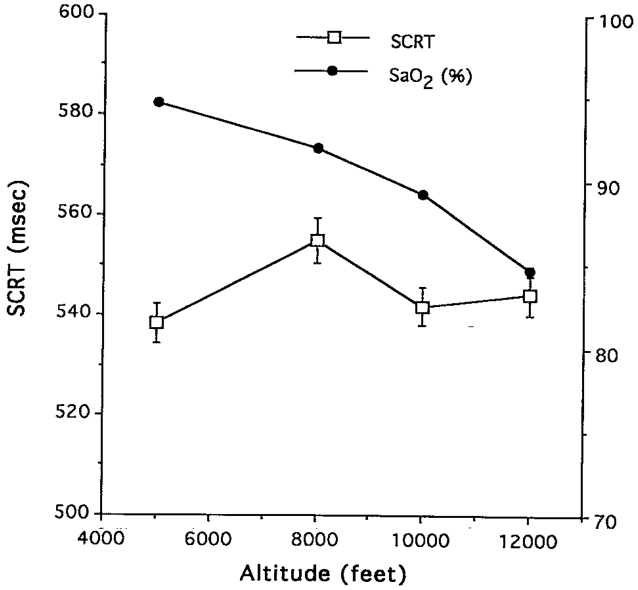

Fig. 8. Plot of SCRT (ms) and arterial oxygen saturation (%) against altitude.

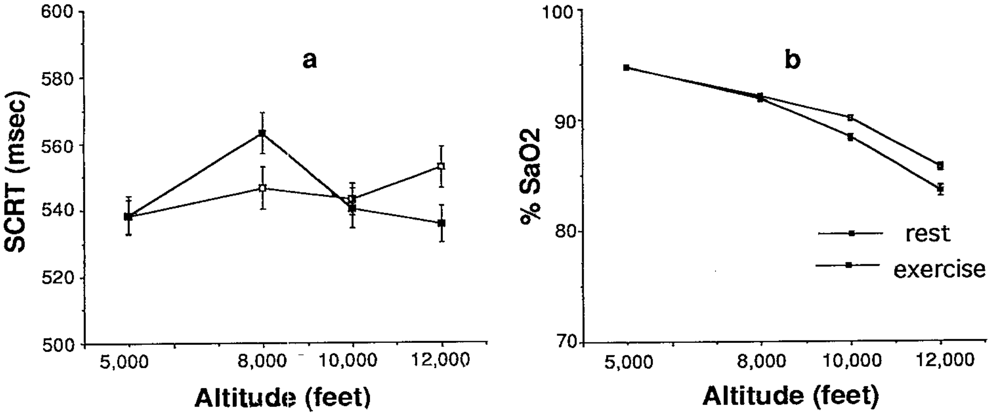

Fig. 9. Plot of SCRT (ms) against altitude for resting and exercising subjects (a). Plot of % Sa_{O_2} against altitude for resting and exercising subjects (b). Open squares correspond to resting subjects; closed squares correspond to exercising subjects.

fected by exposure to a range of mild acute hypoxias in an altitude chamber, and to assess whether light exercise (27 W) modifies Sao_2 and performance at these altitudes.

We were unable to confirm the results of Denison et al. (5) who reported that subjects who had one Manikin session at ground level prior to their altitude exposure performed much better at 8,000 ft than subjects who had their first session at 8,000 ft. In their study, they documented large differences in reaction time between orders of presentation in the first two blocks of trials. These differences of reaction time performance between ground level and altitude subjects in the first block was 1,800 ms, which decreased to about 1,700 ms in the second block, and then to 800 ms and 200 ms in the third and fourth blocks, respectively. Also Denison et al. reported a standard error of 510 ms for their 8,000 ft subjects in block 1 of session 1, while their ground level subjects in block 1 of their first session yielded a standard error of only 210 ms. Both of these groups of subjects yielded standard errors of about 230 ms during block one of their second sessions. Given that Denison et al. had only four subjects in each group and the long average reaction time of the four subjects in the 8,000 ft first group had an associated standard error that was two and a half times the standard error of the other groups in their study, it is not unreasonable to conclude that one of their subjects was an outlier, possibly because of apprehension due to the novel altitude chamber environment.

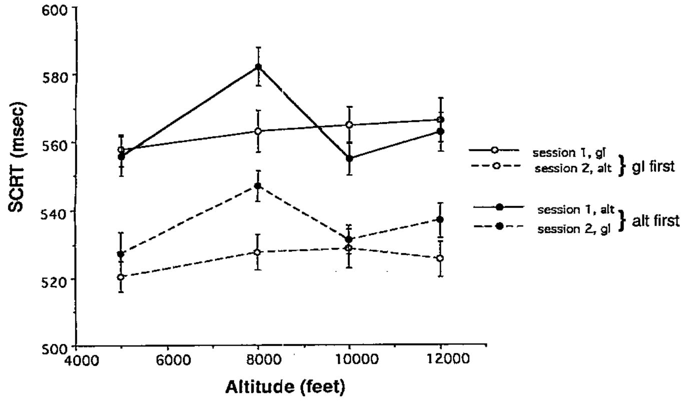

Fig. 10. Plot of SCRT (ms) against altitude. Legend as in Fig. 4.

The Manikin reaction time difference in our study was 225 ms (collapsed over blocks) vs. about 1,400 ms (collapsed over blocks) in the study by Denison et al. We did not detect a similar effect as Denison et al. with the Manikin Task, or with the two other performance tasks at 8,000 ft or at the three other altitudes used in this study.

With respect to the main effect of altitude, reaction time to the manikin increased by about 80 ms from 5,000 ft to 8,000 ft, and thereafter remained relatively constant (Fig. 3). Subjects performed better in their second sessions than in their first sessions, whether at ground level or altitude (Fig. 4). Both the LRT (Fig. 5) and SCRT (Fig. 8) tasks showed a quadratic effect with respect to altitude with performance affected at 8,000 ft, but not at 5,000 ft, 10,000 ft, or 12,000 ft. A similar biphasic response to altitude has also been observed by Ledwidth (16) and Kennedy et al. (15) with performance tasks, as well as by Fraser et al. in postural stability (8), and Fraser et al. (9) with vestibular evoked responses. Though the results for the Manikin Task indicate a similar biphasic relationship between performance, altitude, exercise, and order of presentation (Fig. 4), the variability between groups, as indicated by the ground level data for session 1 at both exercise and rest, is greater than the effects of altitude. In an attempt to put into perspective the 20-ms decrement on SCRT performance of our 8,000 ft subjects compared to their ground level counterparts (Fig. 8, Fig. 9, first sessions of Fig. 10, and Fig. 11), we reviewed the work of Maylor et al. (17), who also used untrained subjects to assess the effects of alcohol on SCRT performance. They found that a blood alcohol level (BAC) of 130 mg% decreased SCRT performance by 40 ms, while a BAC of 28 mg% improved SCRT performance by 5 ms. Based on the Maylor et al. results, we feel that the 20-ms SCRT decrement we found at 8,000 ft might be comparable to an SCRT performance decrement caused by a BAC of approximately 80 mg%.

With respect to the Manikin Task, we found a significant learning curve (Fig. 2) but no differences in learning over any of the four test altitudes, two orders of presentation, or the two levels of exercise. We did not find any improvement in performance over blocks during the LRT task which indicates that skill acquisition in this task is a more difficult proposition than skill acquisition in the other two tasks. We found a demonstrable

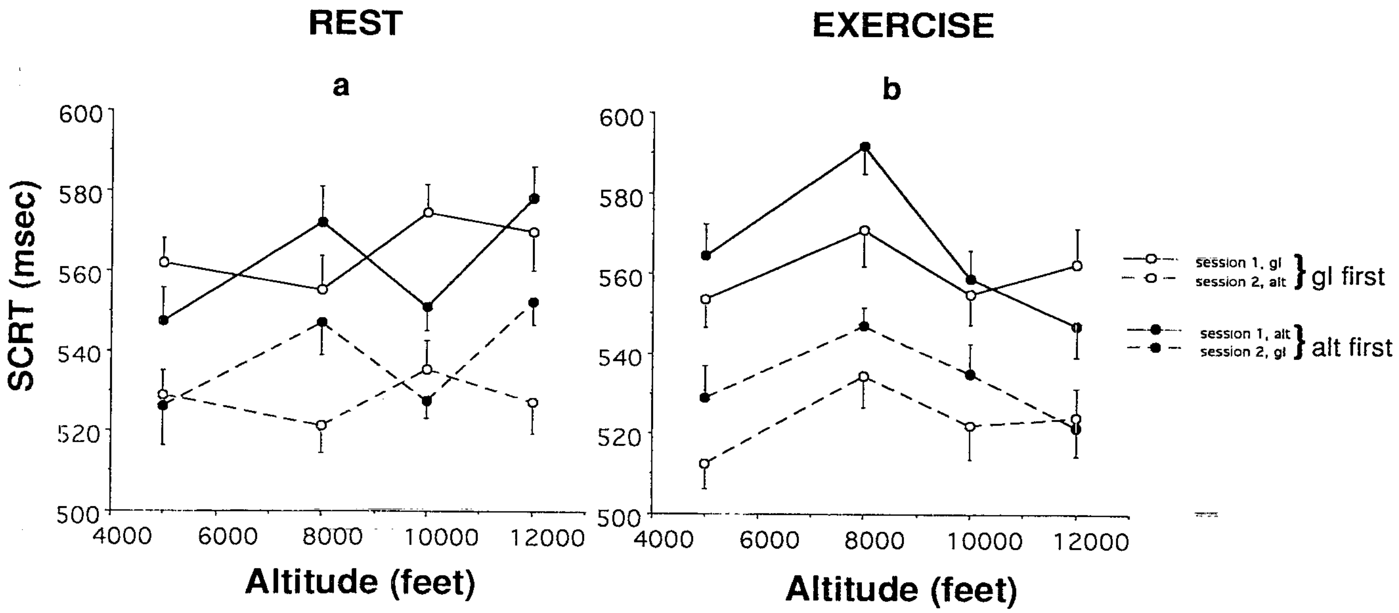

Fig. 11. Plot of SCRT (ms) against altitude for resting (a) and exercising (b) subjects. Legend as in Fig. 4.

learning curve for the SCRT task (Fig. 7), but again no differences in learning over any of the four test altitudes, or the two orders of presentation, or the two levels of exercise.

During the Manikin Task, resting subjects performed marginally faster than their exercising counterparts. During the LRT task, exercise also tended to slightly affect performance in that the resting subjects almost completed one problem more than their exercising counterparts. The SCRT was the only task where exercise did not tend to reduce performance. That we found a statistically significant 3 ms improvement in serial choice reaction time with exercising subjects when compared to resting subjects and a 6-ms reaction time advantage for ground-level-first subjects over their altitude-first counterparts is due largely to the minimum variability of the data for this test. Given that Denison et al. did not use resting subjects as a control for their exercising subjects, exercise was not a factor in their study.

As for Manikin Task performance, subjects performed better in their second sessions for both orders of presentation (Fig. 4). During the LRT task (Fig. 6) as during the Manikin Task, the variability in ground level data for session 1 at both exercise and rest, is greater than the effects of altitude.

Fig. 11 separates out the effect of exercise from the effects of altitude which reveals that SCRT performance for resting subjects did not change much across altitude (approximately 15 ms from 5,000 ft to 12,000 ft) while SCRT for exercising subjects increased by 25 ms from 5,000 to 8,000 ft, and at 10,000 ft recovered to the values at 5,000 ft, and continued to improve by another 5 ms at 12,000 ft. This improvement in performance for exercising subjects from 8,000 ft to 12,000 ft occurred in spite of the fact that these subjects were more hypoxic (on the basis of Sa_{O_2}) than their resting counterparts (Fig. 9). Fig. 10 shows the anticipated improvement from session 1 to session 2 for both orders of presentation. The altitude-first subjects show a decrement from 5,000 ft to 8,000 ft, followed by a recovery in performance at 10,000 ft and 12,000 ft. These subjects exhibit the same biphasic response when they are assessed at ground level (their second sessions) which suggests state dependent learning in that these subjects carry over their learning pattern from altitude to their ground level session. The ground-level-first subjects carry over their first session experience (ground level) to altitude in that both of their curves are linear. As for both the Manikin Task (Fig. 4), and the LRT task (Fig. 6), SCRT performance was better in the second session than in the first session (Fig. 11).

With respect to other studies which state that hypoxia impairs performance at 8,000 ft, Billings (3) used the Gedye task (a psychomotor task involving recent memory where the dependent variable was the time to respond to a series of left-right light sequences) to study learning. The author stated that learning may be impaired at 8,000 ft, but he made no attempt to test his data statistically and the graph of response times to the Gedye task over trials appears to indicate that the air and oxygen performance curves are virtually identical. A study by Kelman and Crow (14) used a visual search task where the subjects were presented with pages of random text containing alphabetical characters. In the less difficult version of the test, the subjects were required to mark wherever the same letter occurred in two adjacent positions (AA, BB, CC, etc.), while in the more difficult version they were required to indicate where pairs of letters occurred in alphabetic order (AB, BC, DC, etc.). With the easier version there was no significant difference between performance at the control altitude (2,000 ft) and 8,000 ft, while with the more difficult test, initial performance was significantly worse at 8,000 ft, but with practice the difference between altitude and control groups disappeared. On the other hand, Kelman and Crow carried out subsequent experiments which did not yield significant results. A card sorting task (where various numbers of alphabetical

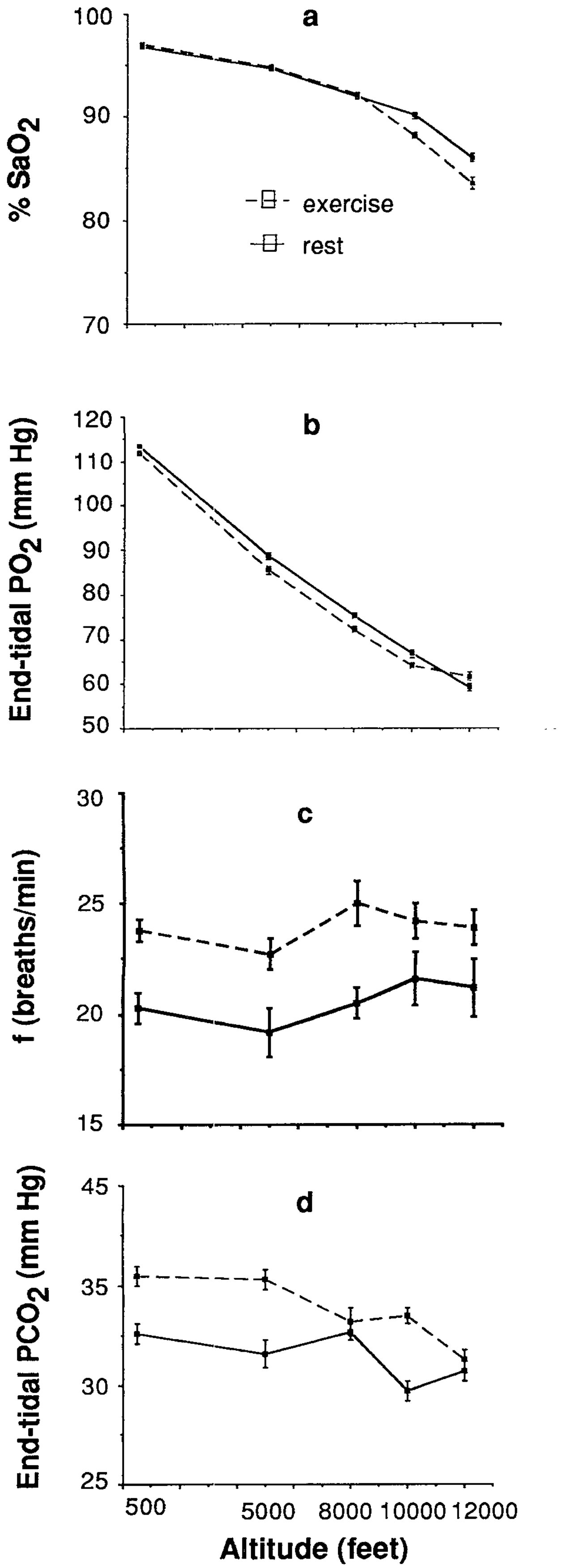

Fig. 12. Plot of percent Sao_2 (a), end-tidal Po_2 (b), respiratory frequency (breaths/min) (c), and end-tidal Pco_2 (d) against altitude. Solid lines correspond to resting subjects; dashed lines correspond to exercising subjects.

characters were printed on the faces of the cards) was employed in one study (13). The dependent measure, in this double blind separate group design, was the time taken to sort 12 packs of cards. The altitude group tended to perform better than the control group but the results fell short of significance. In their next study (4), using a similar design, the subjects were required to recall sequences of six digits randomly selected and presented via headphones at a rate of one digit per second. After a variable interval of time (2, 4, 6, 8, 16, or 32 s) the subjects tried to recall and write down the appropriate digit sequence. The interval between the end of presentation and recall was filled with a shadowing task during which the subjects were required to write down letters randomly selected from the alphabet as they were presented. Recall error rate increased with increasing interval for both the 2,000-ft control altitude and 8,000-ft experimental altitude, but there was no difference between groups at either altitude. In summary, our results do not support the results of Billings (3), Denison et al. (5), or Kelman and Crow (14), but are consistent with the results of Crow and Kelman (4) and Kelman, Crow, and Bursill (13).

With respect to our physiologic results, the expected decrease in Sao_2 with increasing altitude is evident. At 10,000 and 12,000 ft, the exercising subjects are more hypoxic than their resting counterparts, even though at 12,000 ft the end-tidal Po_2 values for exercising subjects are higher than for resting subjects, which probably reflects a threshold altitude-induced compensatory increase in ventilation. Respiratory frequency is higher with increasing altitude and higher in exercising subjects than in resting subjects. These breathing frequency curves are reflected in the corresponding decrease in end-tidal Pco_2 with exercise and increasing altitude. The small differences in Po_2 (2 mm Hg), f (5 breaths • min^{-1}), and Pco_2 (1 mm Hg) between the SCRT task and the other two tasks are probably due to the arm exercise component inherent in the SCRT task which is not present in either of the Manikin or LRT tasks. Overall, these physiologic parameters indicate that the small performance differences found in this study are not a function of severity of hypoxia as measured by Sao_2, given that in several cases the more hypoxic subjects (exercising subjects) performed better than their less hypoxic (resting) counterparts.

We conclude that there is no measurable decrement in the ability of naive subjects to learn any of the three tasks used in this study at altitudes up to and including 12,000 ft. We did, however, detect a biphasic response to altitude in LRT and SCRT performance, but not for Manikin performance. This biphasic response was not seen in any of the physiological measures. Exercise lowered the Sao_2 of the subjects at altitude, and there was an interaction between exercising and altitude on all three tasks.

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