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THE EFFECTS OF 12 HOURS OF LOW GRADE HYPOXIA AT 10,000 FT AT NIGHT IN SPECIAL OPERATIONS FORCES AIRCRAFT OPERATIONS ON COGNITION, NIGHT VISION GOGGLE VISION AND SUBJECTIVE SYMPTOMS

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14. ABSTRACT This study evaluated the effects of extended exposure to low-grade hypoxia on cognitive function and visual performance (unaided and night vision goggle [NVG] visual acuity). Thirty subjects were exposed to two, 12 hour exposures, one at ground level and another at 10,000 ft altitude in a hypobaric chamber. Half of the subjects performed moderate exercise. Results: Twelve hour exposure at 10,000 feet produced no significant negative impact on cognitive function, but minor negative effects on night vision goggle performance under operational lighting (starlight) conditions. The altitude exposure did not negatively affect unaided night vision performance under twilight lighting. There was a slight increase in self-reported symptoms of headache, fatigue and lack of concentration, but there was no increase in reported symptoms with the moderate exercise. The increased reports of headache at altitude may possibly indicate imminent mild acute mountain sickness.

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Low grade hypoxia, extended low altitude exposure, cognitive performance, night vision goggle vision, moderate exercise, headache, acute mountain sickness

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SUMMARY

Purpose: The primary objective of this study was to evaluate the effects of extended exposure to low-grade hypoxia on cognitive function and visual performance (unaided and night vision goggle [NVG] visual acuity). To achieve this objective, comparisons of cognitive and visual performance at near ground level altitude pressure and at a 10,000 foot (3048 meters) altitude pressure were made over a 12 hour exposure, reasonably approximating the operational envelope and mission time flown by the special operations community. The study also evaluated the potential effect of moderate physical exercise on cognitive and visual performance at altitude and symptoms of hypoxia and acute mountain sickness.

Methods: Thirty subjects were exposed to two, 12 hour exposures, one at ground level and another to 10,000 ft altitude pressure in a hypobaric chamber. Half (15) of the subjects performed moderate exercise on a cycle ergometer for 10 min every other hour at both pressure levels. The interior of the chamber was kept dark, except for the computer screen illumination during the performance tests, to facilitate dark vision adaptation and simulate operational conditions. Oxygen saturation, heart rate, and cognitive performance (Two Choice Test, Tower Test, Continuous Performance Test, Grammatical Reasoning Test, Mathematical Processing Test, Match to Sample Test, Spatial Processing Test) were measured. The subjects had to indicate their subjective symptoms on hypoxia and acute mountain sickness questionnaires. Visual performance was measured using night vision goggles with Bailey-Lovie Visual Acuity tests, Pelli-Robinson Contrast Charts and the Unaided Visual Acuity with low and high contrast charts.

Results: Blood oxygen saturation decreased at 10,000 ft, but remained stable during the 12 hour exposure. The mild hypoxia experienced at 10,000 feet (3048 m) equivalent altitude for 12 hours produced minimal influence of low-grade hypoxia on cognitive performance and NVG vision. No significant negative impact on cognitive function was found, but minor negative effects on night vision goggle performance under operational lighting (starlight) conditions were registered. The altitude exposure did not negatively affect unaided night vision performance under mesopic (twilight) lighting. There was a slight increase in self-reported symptoms of headache, fatigue and lack of concentration, but there was no increase in reported symptoms with the moderate exercise.

Conclusions: No negative effects on cognitive performance were found and minor negative vision effects occurred at 10,000 ft. The increased reports of headache at altitude may possibly indicate imminent mild acute mountain sickness.

INTRODUCTION

OBJECTIVE.

This study's primary objective was to evaluate the effects of extended exposure to low-grade hypoxia on cognitive function and visual performance (unaided and night vision goggle [NVG] visual acuity). To achieve this objective, comparisons of cognitive and visual performance at near ground level altitude pressure and at a 10,000 foot (3048 meters) altitude pressure were made. Comparison data sets were acquired over a continuous 12 hour exposure, reasonably approximating the operational envelope and mission flown by the special operations community. Additionally, the study examined a secondary objective to evaluate the potential effect of increased physical exertion (exercise) during altitude adaptation on cognitive and visual performance.

BACKGROUND.

The hypothesis was that extended (12 hours) exposure to low oxygen (hypoxia) and exercise when encountered at 10,000 feet above mean sea level (MSL) equivalent altitude would detrimentally affect cognitive performance and/or visual performance due to fatigue and the physiological effects of hypoxia.

The scientific rationale for this study involved a safety concern facing the special operations community today in that many of their operations are conducted in un-pressurized aircraft (Special Operation Forces C-130s, various helicopters, and the CV-22) at low (10,000 foot or lower) altitude, at night while wearing NVGs and under varying workload conditions for extended periods of time. Most of these un-pressurized flights are flown without supplemental oxygen in accordance with current USAF policy. The general consensus among aircrew is that hypoxia is not a factor below 10,000 ft MSL. However, the effects of low-grade hypoxia exposure at various workloads and during night conditions for up to 12 hours and its role in aircrew performance and flight safety after prolonged exposure have not been adequately assessed.

USAF policy on supplemental oxygen use. During the 1950s and 1960s, the use of supplemental oxygen was **required** from the ground up on all tactical and combat night flights (Air Force Regulation (AFR) 60-16, 1953; Air Force Pamphlet (AFP) 161-16 Physiology of Flight 1968). The practice of supplemental oxygen use from ground level during night flying operation changed with the rewrite of "AFP 161-16 Physiology of Flight" when it became "AFP 160-5 Physiological Training" dated 1976. At this time, the reference to a requirement for supplemental oxygen use during night flying operations was removed from the text. Reasons for this change could not be identified. From then on, the regulations governing flying operations in un-pressurized aircraft made no reference to the use of supplemental oxygen being required until the aircraft altitude exceeds 10,000 ft. In addition, there is currently no distinction made concerning day vs. night flying operations in any Air Force Instruction (AFI).

The current policy for C-130 High Altitude Airdrop Missions (HAAMS) and the use of supplemental oxygen during un-pressurized flight is covered in "AFI 11-2C-130V3", which states, "A continuous supply of 100 percent oxygen will be used by all personnel during un-pressurized operations above 10,000 ft MSL. Crewmembers will follow established MAJCOM oxygen mask requirements." Note that no reference is made to operations for night flying or the use of supplemental oxygen on any other mission type than HAAMS conducted in the C-130. The current MH-53 policy ("AFI 11-2MH-53V3") for un-pressurized flying operations states: "Flight operations above 10,000 ft MSL without supplemental oxygen shall only be conducted when mission essential. Comply with AFI 11-202 Vol. 3." "AFI 11-202V3 Flying Operations" makes only one general statement regarding unpressurized flight: "Each crewmember shall use supplemental oxygen anytime the cabin altitude exceeds 10,000 ft." An exception for helicopter operations was added in the 9th February 2001 rewrite to allow for unpressurized flights without supplemental oxygen above 10,000 ft. Again there was no reference made to use of supplemental oxygen during night flying operations under this policy change.

Cognitive performance. Research has shown that certain cognitive tasks are affected at altitudes well below 10,000 ft when breathing ambient air. Impairment on task learning, reaction time and reasoning abilities has been shown at altitudes as low as 5,000-6,000 ft. Ernsting (1984) recommended 6,000 ft as maximum altitude for operations without oxygen. This was based on the thought that a decrement in the learning phase of a complex task is barely detectable at 5,000 ft, and is considerable at 8,000 ft. Ernsting also found that short-term and long-term memory tasks are affected when breathing air at 8000-10000 ft. This would be important to the aircrew if they were forced to perform a novel task. Such improvising is common in the missions of Special Operation Forces. On the other hand, Pearson and Neal (1970) showed that hypoxia associated with breathing air at altitudes of 8,000-10,000 ft has no detectable effect on performance if the task was well learned first at ground level. Using manikin tasks up to 12,000 ft, Denison (1966) found a significant effect on rate of learning suggesting that hypoxia affected learning and memory at lower altitudes such as 8,000ft. Green and Morgan (1985) then attempted to reproduce the previous work, but were unable to support Denison's findings. Kelman and Crow in a series of studies (1969, 1971, 1973) reported memory and learning were not affected by hypoxia at any altitude below 12,000 ft. Barry Fowler et al. (1985) also came to the conclusion that the minimum altitude at which hypoxic performance decrements can be detected is greater than 8,000 ft. Fowler had doubts about the "task novelty" hypothesis as well. He found too many confounding variables in Denison's early work. He believed that reaction time decrements seen at an altitude of 8,000 ft could be attributed to "task novelty" because the effect could not be seen anywhere but at the beginning of testing. Nesthus (1997) also attempted to clear up the debate by using flight relevant tasks with simulated altitude using the Multiple Attribute Task Battery to test cognition. This task battery incorporated time-shared performance on several sub tasks under experimenter manipulated workload conditions such as monitoring of dials and displays with dynamic tracking tasks and multiple resource management testing. Ten pilots in a mild hypoxia group and a control group were compared in measures of simulated flight performance and flight-following procedures during a 3-day, 2-hr/per day, cross-country scenario. Significantly more procedural errors were committed by the hypoxia group during simulated cruise flight at 10,000 ft, both during the descent and approach phases from 10,000 ft, and during descent from 12,500 ft. This suggests that there can be a significant effect on pilot performance from hypoxia at altitudes lower than 10,000 ft. Angerer and Nowak (2003) also report one study in which subjects were exposed to 10,000 ft (3,048 m) for 6.5 hours and found performance decreased by 10 to 20% at one or more time points for arithmetic, reasoning, long and short-term memory, perceptual speed and visual reaction time. Except for short-term memory, no relationship was found with the duration of an exposure and some tests revealed large individual differences. A recent study by Pavlicek et al. (2005) which assessed the effects of hypoxia on subjects exposed to altitudes of 3000 m or 4500 m for two hours found no significant change in higher cognitive and emotional function tests suggesting short-term adaptation mechanisms (addressed below) may lead to preservation of these functions. Finally, a precursor study to this study conducted by Balldin et al. (2005) which looked at cognitive and NVG performance at 5,000, 8,000, and 12,000 ft equivalent altitude also found no to very minor and clinically irrelevant decreases in cognitive performance and no decrements in NVG performance. Getting an accurate picture of the effects of low altitude on cognitive performance is complicated by the slightly different cognitive tests, altitudes and durations of exposure. However, the most disparate variable in these studies with respect to modern special operations missions is duration of exposure. Most of the altitude exposures were relatively short (≤ 2 hours) while others, such as the Angerer and Nowak study, ended at the time where acclimation to altitude may start to play a more significant role on cognitive performance. Therefore, the need to understanding the effects of prolonged (12 hours) exposure to low grade hypoxia on cognitive performance is still not adequately resolved.

Night vision performance. The research available on low-grade hypoxia and NVG visual performance is limited. Therefore, further research is required to determine if there is a measurable decrease in visual performance that may impact flight safety. During the past 62 years, McFarland and Halperin (1940) reported decrements in scotopic visual sensitivity of at least 5% at 3,500 ft, 20% at 10,000 ft, and 35% at 13,000 ft in the absence of supplemental oxygen. They also demonstrated that scotopic visual sensitivity and dark adaptation can be degraded at altitudes as low as 4,500 ft, and that by 12,000 ft, this decreases to approximately 60% of that observable at sea level. However, night vision goggle output luminance levels are well above scotopic ranges and are in fact in the transitional mesopic (rod-cone) to near-photopic (cone) ranges, where the cones are more resistant to hypoxic effects. Leber et al. (1986), using four subjects and the Generation II AN/PVS-5 system showed that the lack of oxygen degraded unaided visual acuity to a much greater degree than NVG visual acuity. While mild hypoxia significantly affected unaided visual acuity, it did not significantly affect NVG performance up to 13,000 ft ASL. Potential confounders in Leber's study included subjects that were already acclimatized to 5,350 ft and the use of gaseous mixtures to simulate altitude effects. In this study, supplemental oxygen did not significantly improve NVG performance at altitudes lower than this, whereas it did improve naked-eye acuity. This suggested, but did not clearly establish that oxygen supplementation for NVG aided visual resolution up to 13,000 ft was not indicated. Another study by Davis et al.(1995) using 17 subjects and the Gen III ANVIS, evaluated visual acuity and contrast sensitivity at an altitude under starlight and full-moon illumination, at sea level, 5 and 30 minutes after reaching 14,108 ft (4,300 meters), then again at 10 minutes after returning to sea level. They demonstrated that visual acuity with ANVIS goggles was slightly degraded (an average of 2.5 letters) after 30 minutes of exposure at 14,108 ft, but contrast sensitivity on Pelli-Robson charts was not. Males and females performed similarly. This study indicated that supplemental oxygen was helpful at that altitude using NVGs, although duration of use and specific altitude thresholds were not determined. USAFSAM's study done by DeVilbiss (1998) using 15 subjects and Gen III ANVIS-6 goggles, investigated performance at simulated sea level, 5,000, 10,000, 15,000, 18,000, and 20,000 ft. In this experiment, three target contrasts (high, medium, and low) were used and two supplemental oxygen settings were employed (normal and 100%). Contrast sensitivity was measured with "no supplemental oxygen" conditions. This study demonstrated that NVG performance at 10,000 ft altitude was degraded without supplemental oxygen as compared to both 100% and normal supplemental settings. However, at the two lowest altitudes (sea level and 5,000), the "no supplemental oxygen" condition did not differ significantly from the two supplemental oxygen conditions. In addition, at all altitudes tested, there were no significant differences between the two supplemental oxygen settings. DeVilbiss concluded that visual performance using NVGs at 10,000 ft with no supplemental oxygen was significantly decreased, while visual performance was equal at 20,000 ft with either normal or 100% supplemental oxygen. In summary, it appears overall that high contrast visual acuity and contrast visual acuity in an unaided observer benefit from supplemental oxygen with increasing altitude. However, NVG acuity appears to remain stable (in at least two studies, to levels of 10,000 and 13,000 ft respectively). It seems prudent, and indicated, that at flight levels above 10,000 ft supplemental oxygen would provide insurance against any potential degradation in NVG acuities, but that at or below 10,000 ft, this premise has not been supported from the limited literature studies available thus far. Finally, the above mentioned USAFSAM/AFRL study (Balldin et al. 2005) specifically looked at cognitive and visual performance effects of low-grade hypoxia. In this study, 92 subjects were exposed to four simulated altitudes (ground level, 5,000, 8,000, and 12,000 ft). The results indicated a minimal influence of low-grade hypoxia on cognitive and NVG performance. However, the effects of extended hypoxic exposures at altitude (and of exercise) on cognitive and visual performance was not evaluated.

Altitude acclimatization. Acclimation to altitude involves three overlapping phases as described by Hochachka (1998): acute, acclimatory and genetic or phylogenetic (phylogenetics is not relevant to this study and will not be discussed). The acute response is the result of physiological changes in the body to increase the oxygen uptake in the lung. This response occurs within minutes of exposure. The two main acute responses are the hypoxic ventilatory response, which is simply an increase in the breathing rate per minute, and the hypoxic pulmonary vasoconstrictor response which causes the blood vessels in the lungs to constrict thereby raising the pulmonary blood pressure. The increase in blood pressure in the lungs and the brain can be a precursor to problems in people who are not altitude adapted and ascend too rapidly. These are known as acute mountain sickness (AMS), high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE). While potentially life threatening, HAPE and HACE are not common and generally take several days to develop (Muza et al, 2004; Roach and Hackett, 1993). Acute mountain sickness is not life threatening but more common and can occur within a relatively short time. Symptoms include headache, nausea, vomiting, fatigue, dizziness and insomnia (Muza et al. 2004, Angerer et al. 2003, Roach et al. 1993). Muza et al. also report the onset time for the symptoms of AMS range from 6 to 24 hours and is dependent upon the ascent rate and altitude. Further, he reports that the incidence rate of AMS for subjects at 10,000 feet is as follows: mild 20% to 30%, moderate 10% to 20% and severe 0% to 10% with symptom rates increasing with physical workload. The acclimatory phase begins within several hours of altitude exposure. It is this phase which begins the physiological adaptation to high altitude, inducing changes to the body that will allow it to function better at altitude. A component of early acclimatory adaptation is the release of erythropoietin (EPO) by the kidneys and liver and by astrocytes in the brain. EPO has long been known to stimulate the production of red blood cells to increase the oxygen carrying capability of the blood. Levels of EPO begin to increase within hours of exposure to a hypoxic environment with the most dramatic increase starting about 6 hours after exposure and continuing to rise for the next 24 hours (Ri-Li et al. 2002, Samaja 2001). In the Ri-Li et al study subjects exposed to various altitudes ranging from 1,780 m to 2,805 m all showed increases in EPO production with the higher altitudes inducing even greater EPO production. However, there was a significant variation among individuals. Observations that red blood cells do not begin to increase in the blood stream until about five days after EPO release led researchers to question if EPO served another purpose early in the exposure. Indeed, as reported by Samaja, EPO does appear to play a significant role in protecting tissues from hypoxia induced cell damage by inhibiting inflammation and cell death (apoptosis). Therefore, EPO may protect cognitive and visual function from hypoxia and thus explain the discrepancies in cognitive performance seen in previous studies which varied in altitude and duration. Extending the duration of hypoxic exposure to 12 hours at 10,000 ft will enable more pronounced acute and acclimatory response phases and allow better assessment of this response to cognitive and NVG visual performance.

Exercise at altitude. Hiking in the mountains can be rather strenuous due to increased demand for oxygen while exercising in a hypoxic environment. This situation is no different for special operations aircrew performing physically demanding duties during unpressurized flight that do not permit the easy use of supplemental oxygen. For example, AC-130 weapons loaders routinely operate under physically demanding conditions; loading munitions weighing up to 40 pounds for extended periods. The demand for more oxygen creates a situation known as physiological altitude wherein the oxygen levels available to the brain and eyes are equivalent to that of a higher altitude because of the increased use of oxygen by the muscles. As reported (Muza et al. 2004, Angerer et al. 2003, Roach et al. 2001), exercise induced oxygen demand also decreases the onset time of acute mountain sickness. Therefore, aircrew with higher physical workloads may experience greater cognitive and visual decrements, and be at greater risk for developing AMS, during flight durations and altitudes that would typically not be of great concern for aircrew with low workload demands.

Fatigue. The effects of long duty hours can lead to fatigue and a decrease in operational and cognitive performance (Miller 2005). By its very nature, hypoxia causes a reduction of available oxygen for energy production and, therefore, fatigue. Combined, these two conditions would be expected to have synergistic detrimental effects although the extent of this detriment to cognitive performance, night vision goggle performance and even altitude adaptation on aircrew is unknown.

METHODS.

Equipment and facilities. The hypobaric exposures were conducted in a hypobaric chamber used during many years of human decompression studies at Brooks City-Base, Texas. These facilities had the necessary safety monitoring equipment and communications pass-through ports.

Subjects. Thirty (30) fully informed, non-smoking, active duty military female and male personnel volunteered for this protocol, which included ground-level training and testing. The subjects were 23 to 45 years old (mean age 33.0 years) and gave informed consent to participate in the study. All subjects met medical requirements for a USAF class III flight physical. The subjects were screened for evidence of conditions which might abnormally impair their tolerance to altitude. Pregnancy tests within 36 hours prior to each altitude exposure were required for female subjects.

Duration: Subjects participated in one day (~4 hours) of ground-level physiological training and training altitude exposure, two days of computer training sessions (1.5 hr per session,) one day of near ground level (1,100 feet sham flight) testing and one day of chamber exposure testing to a maximum of 10,000 ft. The duration of the altitude exposure was 12 hours. Total time for each test day lasted ~13 hours in order to conduct pre- and post-chamber testing.

Description of experiment, data collection, and analysis.

a) Briefing and training. The subjects were not allowed to be involved in scuba diving, or other hyperbaric exposures, for 48 h prior to the hypobaric exposures. Each subject was trained prior to study condition as stipulated in the Informed Consent Document (ICD), to include an orientation exposure and instruction on use of oxygen equipment.

b) Pre-exposure. Prior to each altitude test session, the subject completed a brief medical evaluation. This exam is standard practice for all human subjects exposed to altitude. The subjects were reminded of the presentations of hypoxia and acute mountain sickness and of the need to report any symptoms promptly. Subjects were advised to eat breakfast the morning of each exposure, which was low in protein, gas-producing foods, and fat. During the testing sessions; breakfast, lunch, dinner, snacks and drinks were provided to maintain adequate energy levels and hydration.

c) Ear and sinus check. The subjects accomplished an ear and sinus check in the pressure chamber to a pressure altitude of 5,000 ft at a rate of 5,000 ft/min and returned to ground level at the same rate. Time spent at 5,000 ft was less than 5 sec. During ascent and return to ground level, subjects were required to report if they were able to equalize the pressure across their eardrums and to the sinuses. Any reported symptoms were evaluated. If the subject was unable to equalize ear and sinus pressure during altitude changes, they were re-scheduled.

d) Exposure conditions. Ascent and descent were at 5,000 ft/min. Each subject accomplished two 12 hour test sessions; one at 1,100 feet MSL/500 ft above ground level (AGL) and the other at 10,000 feet equivalent altitude. The order of the two test sessions was randomly assigned to each of the 30 subjects, but was balanced such that both orders occurred equally. In addition, subjects were randomly divided into a low or moderate workload group (15 each group). The moderate workload group performed 10 minutes of exercise every two hours on a cycle ergometer up to 70% of maximum aerobic performance (70% VO_{2max}). The low workload group did not perform any cycle exercise. Each test session contained a mix of low and moderate workload subjects. Time between altitude exposures was a minimum of three days to allow re-acclimation to ground level environment.

e) Activities while decompressed. At altitude, the subjects performed the following tests:

Cognitive Performance Battery

Grammatical reasoning, mathematical processing, simple reaction time, spatial processing ability, and short-term memory were assessed with a battery of simple, PC-based, cognitive tests. The test battery required approximately 30 minutes to complete and was administered a minimum of every two hours.

Cognitive testing on a computer using the following Automated Neuropsychological Assessment Metrics (ANAM) tests:

2CHC – Two Choice Test. This reaction time test presented a simple stimulus on the screen: + or *. The participants were instructed to press a specified response key each time the specified stimulus was presented.

ATP – Tower Test: This was a timed test where subjects choose between three stacks of horizontal bars, and stacked them in the middle of the screen so that the longest bars were at the bottom and shortest at the top. Moving the bars between stacks was only allowed so that shorter bars were on top of longer bars. Longer bars were not allowed to be placed on top of shorter bars.

CPT – Continuous Performance Test: Numbers were presented one at a time in the center of the screen. Subjects were asked to continuously monitor the numbers and press a specified key or button if the number on the screen matched the number that immediately preceded it. They were requested to press a different response button or key if the number did not match the immediately preceding number.

GRAM – Grammatical Reasoning Test: This was a linguistic task requiring knowledge of English grammar and syntax. It also required the ability to determine whether various simple sentences correctly described the relational order of two symbols. Stimulus sets were presented one at a time and were screen-centered to reduce differences in visual search times. On each trial, any combination of the symbol trio "#, &, *" was displayed along with two statements correctly or incorrectly describing the order of the symbols as depicted in the example below:

& # *
& before #
& before *

The subject decided whether the statements were true or false and then pressed the corresponding response button.

MATH – Mathematical Processing Test: During this task, arithmetic problems were presented in the middle of the screen. The task involved deducing an answer and then deciding if the answer was greater-than or less-than the number five. Each problem included two mathematical operations (addition and/or subtraction) on sets of three single-digit numbers (e.g., 5 + 3 - 4 = ?). The subject was instructed to read and calculate from left to right and indicate whether the answer was greater-than or less-than five by pressing one of two specified response buttons. The operators and operandi were selected at random with the following restrictions: only the digits 1 through 9 were used; the correct answer may have been any number from 1 to 9 except 5; greater-than and less-than stimuli were equally probable; cumulative intermediate totals had a positive value; working left to right the same digit could not appear twice in the same problem unless it was preceded by the same operator on each occasion (e.g., +3 and +3 are acceptable, while +3 and -3 are not); the sum of the absolute value of the digits in a problem had to be greater than 5.

M2SP – Match to Sample Test: Matching to Sample was a test in which the subject was required to match a block pattern from memory. A single 4 x 4 matrix (i.e., a checkerboard) was presented in the center of the screen as a sample stimulus. For each trial presentation of a matrix, the number of cells that were shaded varied at random. Following a pre-specified time interval, two comparison matrices were presented side by side. One of the comparison matrices matched the "sample" matrix, while the other comparison matrix differed in shading from the "sample" by one cell. The subject's task was to indicate, by pressing the appropriate response button, which matrix matched the "sample" matrix.

SSEQ- Spatial Processing Test: During this test, pairs of four-bar histograms were presented on the monitor. The histograms were presented as pairs and the subject was requested to determine whether they were identical. One histogram was always rotated either 90 or 270 degrees with respect to the other histogram. The subject responded by pressing a specified key or mouse button to indicate that the two histograms were either the "SAME" or "DIFFERENT."

Workload. Subjects were randomly assigned to a low workload group (15 subjects) or moderate workload group (15 subjects). The low workload group performed only the cognitive and NVG tests. The moderate workload group was asked to exercise every two (2) hours. Exercise was performed on a cycle ergometer for 10 minutes. Tension was slowly adjusted every minute until subject heart rate reached 70% maximum heart rate (MHR), which is correlated with maximum aerobic capacity (VO_{2max}), using the standard formula:

MHR = (220 – age) x 0.7

Heart rate was monitored using an electronic heart rate monitor worn around the chest. If 70% MHR was exceeded, tension was reduced and/or subjects were instructed to slow their rate of pedaling until HR reached 70% MHR.

Fluid (water, fruit juice, etc.) intake was allowed as desired and food was provided during the exposures. Subjects received a briefing on the morning of each exposure, which emphasized their responsibility to inform the chamber personnel of any symptoms of hypoxia and/or acute mountain sickness.

e) Endpoints and post-exposure activity. Endpoints of the exposures were completion of the scheduled exposure or development of any unexpected or severe signs or symptoms of hypoxia or acute mountain sickness.

f) Data Collection

Visual Performance Testing. Testing was performed in a light-tight area illuminated by appropriate standardized lighting. When not collecting NVG/visual acuity data, subjects remained in a minimally lit area simulating a night-operational aircraft environment. Subjects were dark adapted for one hour prior to start of testing.

Ocular Evaluation Procedure. Subjects were tested with their prescription eyeglasses, if required to meet USAF vision standards. Contact lenses were not used during test sessions to avoid contact lens related vision changes. Refractive and keratometric data were collected at ground level and at altitude every two hours using a handheld combined autorefractometer and autokeratometer.

Night Vision Goggle (NVG) Procedure. NVG visual performance was measured using a single NVG (ANVIS F4949) mounted on a fixed headrest used only during the NVG test cycle (duration of focus confirmation and data collection). Subjects were briefed on focusing techniques and accomplished hands-on focusing training before test sessions. Prior to each test session, a trained observer focused the NVG (objective and eyepiece lenses) using a high contrast Snellen letter chart (Bailey-Lovie) set at the testing distance (4 meters) and confirmed normal function. The NVG objective lens remained fixed at this setting throughout the test session, while each subject adjusted the NVG eyepiece to their best subjective focus using one of two high contrast Snellen letter charts. One of two high contrast Snellen letter charts (Bailey-Lovie) and one of two gradient contrast letter chart (Pelli-Robson) were used to assess Binocular NVG visual performance, under standardized starlight-equivalent illumination. A Variable Night Sky Illuminator (Hoffman) was set to target radiance of 1.6 e-10.

Visual testing Procedures

Immediately following NVG data collection, binocular unaided visual acuity data was acquired under low illumination conditions using high and low contrast charts (ETDRS). One of two versions of high and low contrast visual acuity charts was used. The chart version was alternated between test cycles to reduce subject's memorization/letter pattern recognition.

Testing Sequence - the Chamber Test Sequence (pre-post flight, at altitude) included:

- **i.** Auto-Refraction/Auto-Keratometry
- **ii.** NVG focus: eyepiece adjusted to subjective best visual acuity
- **iii.** NVG data collection: low contrast (Pelli-Robson - figure 1) and high contrast (Bailey-Lovie – figure 2) under calibrated starlight equivalent illumination.
- **iv.** Un-aided Low Light Visual Acuity: Precision Vision Charts (low contrast – figure 3, then high contrast – figure 4)

Night Vision Goggle Test Charts

Figure 1 - Pelli-Robson

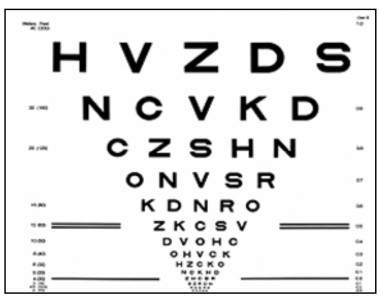


Figure 2 - Bailey-Lovie

Unaided Vision Test Charts

Figure 3 - 5% Contrast

Figure 4 - High Contrast

Physiological Assessments

Subjective Symptom Surveys. At the end of each 1 hour period, participants completed a survey covering subjective symptoms of hypoxia and a survey covering symptoms of acute mountain sickness (every 2 hours). The surveys consisted of a list of commonly known symptoms for the subjects to choose and, if required, extra lines below to list any symptoms they experienced that were not covered on the list.

Blood oxygen saturation. The subjects' blood oxygen saturation was measured every hour with finger oximetry during the simulated altitude exposures. Subjects selected to exercise had their blood oxygen saturation level recorded before and during exercise to determine the extent exercise at altitude affects oxygen saturation levels.

Data Analysis. Before statistical analysis, the data for the *cognitive and visual performance measures* were baseline-adjusted to counter any potential session-to-session differences in an individual's responses. This was accomplished for each cognitive and visual outcome measure by subtracting a participant's baseline value at a given session from the value at each trial in that session. These "deltas" became the data for statistical analysis. A repeated measures analysis of variance (ANOVA) with one between-subjects factor (group—exercise vs. no exercise) and two within-subjects factors (altitude condition—ground vs.10,000 ft, and time—data collection periods within each exposure condition) was performed on each measure. When significant altitude or group effects were detected by the ANOVA, post-hoc simple effects tests were used to elucidate the effects and their time of occurrence. For the *pulse oximetry* data, ANOVAs as described above were performed on the raw data (baseline data were not collected, and therefore no adjustment for baseline was made). Data from the *subjective surveys* was analyzed as follows. For each symptom, each participant's maximum score (i.e., the highest score given to that symptom over the duration of the 12 hour session) was recorded. A Wilcoxon signed rank test was then performed on each symptom to test for an altitude effect. *Statistical Power*. For the primary tests of interest (post-hoc comparisons for the cognitive and visual performance measures), the sample of 30 participants provided an 86% chance of detecting a moderate altitude effect (i.e., a difference of 0.6 standard deviations of the difference in magnitude), and a 75% chance of detecting a larger exercise effect (i.e., a difference of 1.0 standard deviations) when testing at the 0.05 two-tailed alpha level.

RESULTS.

Pulse Oximetry. Descriptive statistics (means and standard deviations at each time point), and the ANOVA results, are presented in Appendix A for oxygen saturation (SaO_2). There was a significant altitude main effect. Figure 5 shows, as expected, that SaO_2 was significantly lower under the 10,000 ft condition than at ground level. SaO_2 levels remained steady over the duration of the session both at 10,000 ft (range: 89.2% to 90.5%) and at ground level (range: 96.4% to 97.4%).

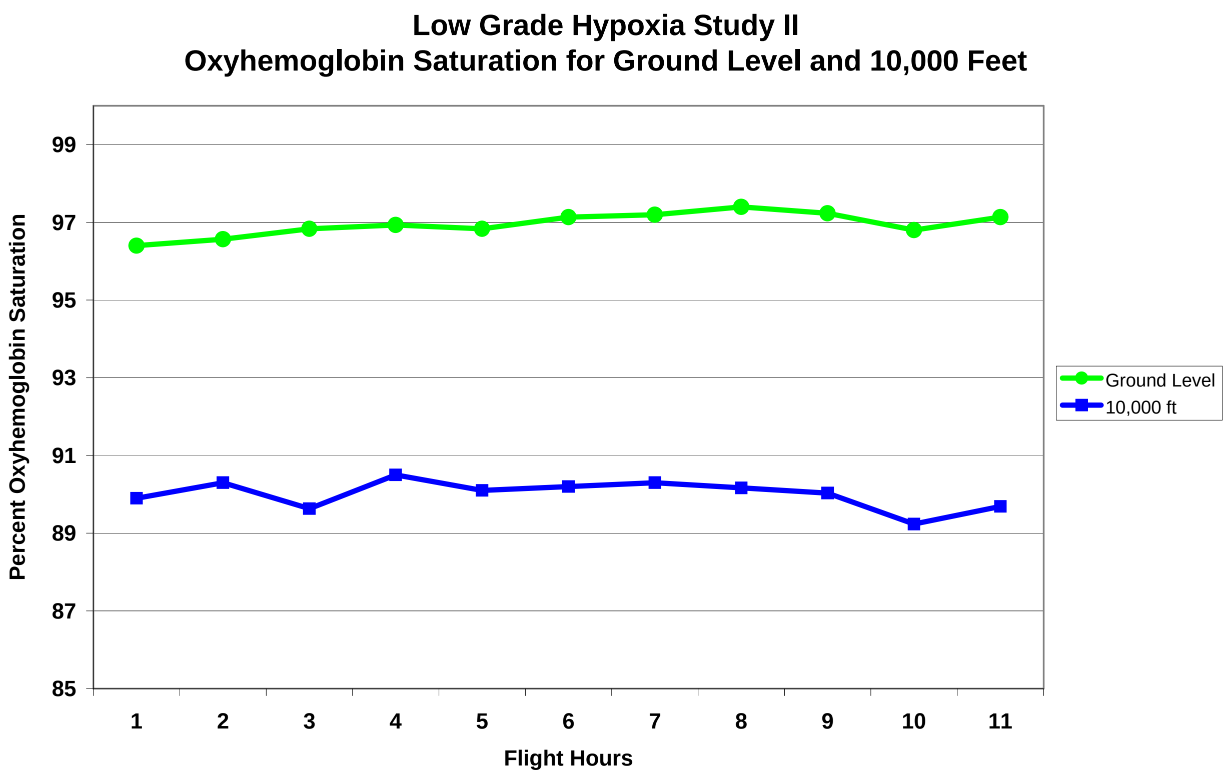


Figure 5. Oxygen saturation recordings at ground level and at 10,000 ft during the 12-hr exposure.

Oxygen Saturation (SaO_2) and Heart Rate (HR) During Exercise. For each individual in the exercise group, the Average Heart Rate, Average SaO_2, Max HR, and Min SaO_2 were calculated for each of the five 10-minute exercise periods. This data was used to test for the effects of altitude while exercising. Descriptive statistics (means and standard deviations), along with the ANOVA results, are presented in Appendix B for each measure.

There were significant time main effects for both Average Heart Rate and Max Heart Rate. Both of these measures showed a slight increase over time for the exercise group (see Appendix B). There was no statistical evidence of an altitude effect for either heart rate variable. As expected, there was a significant altitude effect on Average SaO_2, with levels being lower in the 10,000 ft condition than in the ground level condition across the duration of the exercise sessions. There was also a significant, but small, decrease over time (the largest change from baseline at 10,000 ft was only -0.9% and at ground level the largest change was a mere -0.2%). Min SaO_2 also exhibited a significant altitude effect, with levels lower at 10,000 ft than at ground level for the exercising group. Overall, the magnitude of the difference between 10,000 ft and ground level was about the same as seen for Average SaO_2 (see Appendix B).

Symptom Questionnaire Data As indicated earlier, a Wilcoxon Signed Ranks test was performed for each symptom in each questionnaire to compare the maximum score at 10,000 ft with the maximum score at ground level. Tables I lists the symptoms for which significant differences were found, and shows the percentage of participants who experienced the symptom.

Questionnaire	Symptom	Percent Occurrence at:		Wilcoxon Test	
		10,000 ft	Ground Level	Z-Statistic	p
Acute Mtn. Sickness	Headache	36.7	13.3	-2.83	.005
Hypoxia	Lightheaded	20.0	0.0	-2.33	.020
	Headache	26.7	10.0	-1.90	.058
	Tired	56.7	30.0	-2.05	.041
	Concentration Off	33.3	13.3	-2.14	.033

Note: Only those symptoms for which a significant difference between ground level and 10,000 ft were found are listed in the table.

Table I: Percentage of Participants Experiencing Each Symptom at Least Once During the Experimental Session

Cognitive Performance Descriptive statistics (baseline mean and mean changes from baseline at each time point, along with respective standard deviations) are presented in Appendix C for each cognitive outcome measure. The appendix also contains the ANOVA results and post-hoc test results.

Significant time main effects were seen for 11 of the 14 outcome measures from the five different cognitive tests used in this study. In each of these 11 cases, there was significant improvement in performance over time regardless of the altitude condition. Generally, the improvement started early and continued through the duration of the session (See Appendix C).

A significant exercise by altitude interaction was found for one outcome measure (CPT—MRTC). Post-hoc comparisons did not reveal any specific differences. However, the largest improvement over the duration of the sessions occurred in the exercise group at 10,000 ft, while the smallest improvement occurred in the non exercise group at ground level, with the other two combinations (exercise-ground and no exercise-10,000 ft) falling in the middle, thus resulting in the significant interaction. A significant altitude effect was seen for one outcome measure (Grammatical Reasoning—MRTC). While MRTC generally improved over time for both conditions, the improvement was greater under the 10,000 ft condition. Post-hoc tests indicated that the changes from baseline differed significantly between the ground and 10,000 ft conditions from the 4th hour through the 11th hour of the experimental sessions. No significant altitude or exercise effects were found for any other cognitive performance variable.

Night Vision Data for one subject during the 10,000 ft session was not available. Analysis is therefore based on 29 subjects. Appendix D contains the descriptive statistics (baseline mean and mean changes from baseline at each time point, along with respective standard deviations), ANOVA, and post-hoc test results for each night vision measure.

Night Vision Goggle

Statistically significant altitude and time main effects, and an altitude by time interaction were found in the high contrast Bailey-Lovie test. Figure 6 showed NVG-high contrast visual acuity improved through the 12 hour ground level session, but remained near baseline or lower at 10,000 ft data collection. No significant exercise effect was detected even though Figure 7 shows that non-exercise NVG-high contrast visual acuity tended to improve through the 12 hour session in contrast to the exercised subjects which remained at near baseline until near the end of the test session.

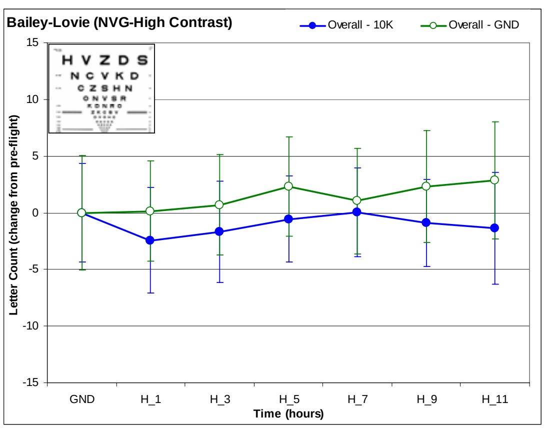


Figure 6: Change-Ground vs Altitude

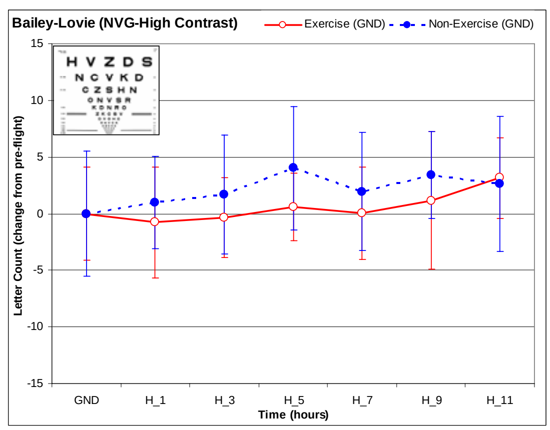


Figure 7: Change–Exercise vs Non-Exercise

The variable contrast Pelli-Robson test revealed statistically significant altitude and time effects. In Figure 8 contrast vision improved over the 12 hours ground level data collection while the contrast vision at altitude remained below, or near, baseline. Figure 9 graphically displays the change in contrast vision performance for the exercise and non-exercise groups. No statistically significant differences were detected between the exercise and non-exercise contrast vision performance.

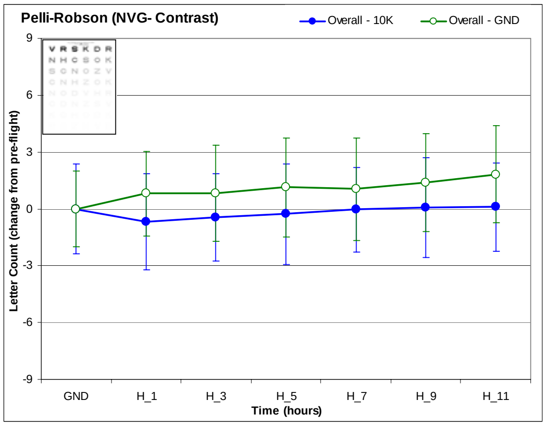


Figure 8: Change-Ground vs Altitude

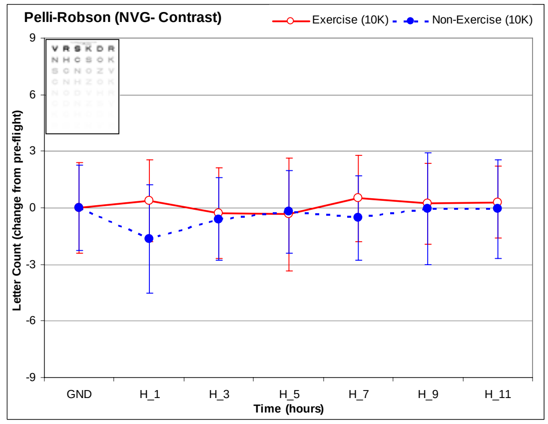


Figure 9: Change–Exercise vs Non-Exercise

Unaided Night Vision

No statistically significant effects due to altitude were detected for the high contrast unaided vision test. Figure 10 shows that the change in responses remained minimal over the 12 hour sessions. The largest difference between the 10,000 ft and ground level readings was only about one letter in magnitude. In contrast to the other visual performance tests, a statistically significant difference between non-exercise and exercise unaided-high contrast visual acuity performance was detected. Figure 11 graphically displays that the non-exercise performance slightly improved as compared to baseline data while for the exercised subjects visual acuity performance remained at slightly below baseline.

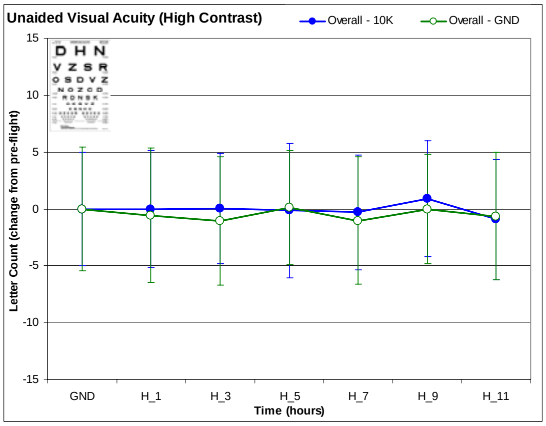


Figure 10: Change-Ground vs Altitude

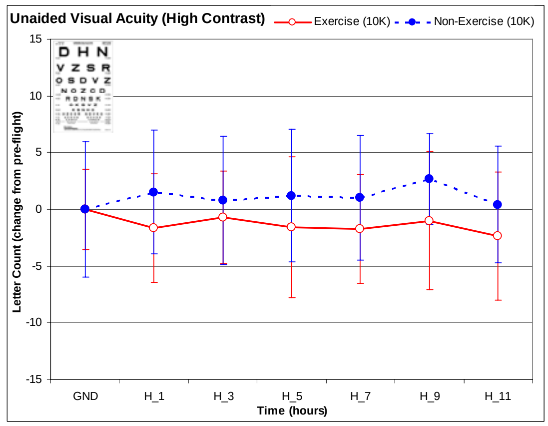
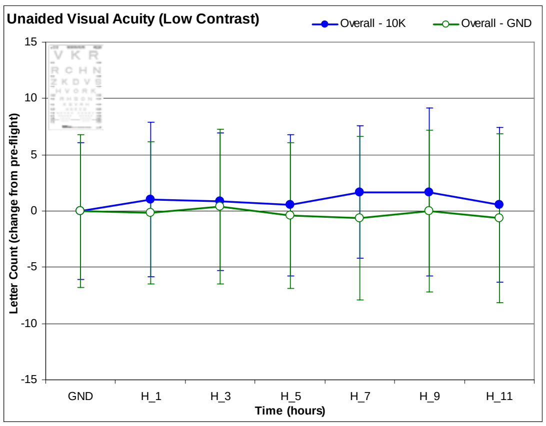


Figure 11: Change–Exercise vs Non-Exercise

For Low Contrast Unaided vision, there was a statistically significant altitude effect. Inspection of Figure 12 notes that participants' vision was slightly better at altitude than at ground level. However, post-hoc testing revealed a statistically significant difference at only one point (7 hours) and that difference was a clinically insignificant 2.5 letter counts in magnitude. Non-exercise and exercise unaided-low contrast visual acuity performance did not show statistically or clinically significant change (figure 13).



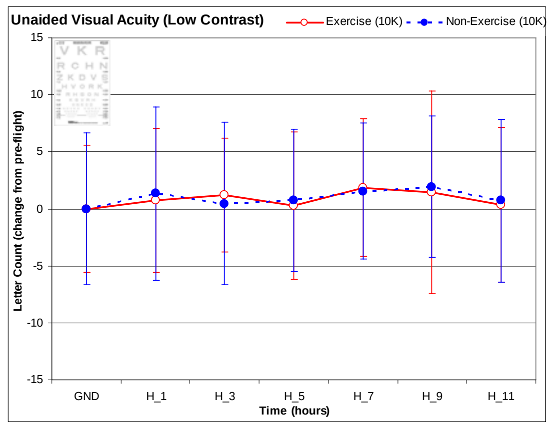


Figure 12: Change-Ground vs Altitude Figure 13: Change–Exercise vs Non-Exercise

DISCUSSION.

The lower initial oxygen saturation at 10,000 ft altitude pressure compared to ground level followed the pattern from numerous earlier studies and what is published in aerospace medical textbooks. However, this study lasting 12 hours at both ground level and at 10,000 ft altitude did not show any change over time of the mean values during the extended period. Similarly, resting heart rate did not show any change over time for the two conditions. This means that a period lasting up to 12 hours will not negatively affect a person at this altitude in these physiological aspects more than what is experienced the first hour of the exposure.

During exercise oxygen saturation showed an altitude effect similar to the effect during rest. For oxygen saturation during exercise there was a small decrease over the 12-hr period. This could possibly be due to a minor fatigue of the muscles, including the breathing muscles, at altitude.

In general, cognitive performance over the duration of the 12 hour study improved under both experimental conditions. This is contrary to what might be expected. That is, one might hypothesize that, over the 12 hours of the session, participants would fatigue or become bored with the test repetitions. There are two likely explanations for this improvement phenomenon. One is that participant performance was simply reflecting the circadian effect. Recall that the participants began their session early in the morning, close to the circadian nadir. The second explanation is that the subjects were not trained to an asymptotic performance level before beginning the session. We suspect that it was a combination of these two effects that produced the results seen here.

It is clear that neither 10,000 ft altitude nor mild exercise negatively impacted cognitive performance over the 12 hours of exposure in this study. There were only two statistical results showing altitude and/or exercise effects, and in both cases the participants' performance was actually better in the "stressor" conditions.

Night Vision Goggle (NVG) and unaided visual performance under low grade hypoxic conditions was first evaluated by the AFRL/USAFSAM study (Balldin et al. 2005) comparing visual performance at four simulated altitudes (near ground, 5000, 8000, and 12,000 ft) and the impact of relatively short exposure at each simulated altitude (about 1 hour) under three illumination conditions (quarter-moon, starlight, and overcast). The results of that study found no statistically significant effects, but trends were observed. It was also noted that no additional information was gained in testing with three levels of illumination. Therefore the current study specifically limited conditions to a single illumination (starlight) and to target evaluation of chronic hypoxic exposure (12 hours).

The AFRL/USAFSAM study (Balldin et al. 2005) observed individual best visual acuity with NVGs varied subject to subject (i.e. between subjects). This has been attributed to factors such as prior experience and individual visual performance with NVG devices. To address these issues, all study subjects completed both 12 hour profiles (ground and altitude). Approximately half of the subjects accomplished the ground data run prior to the altitude data collection and the remaining subjects completed altitude data collection prior to the ground profile. NVG and unaided performance data under test conditions was compared to data collected at ground level just prior to the full test condition.

Analysis of the NVG visual performance found statistically significant differences over time and with altitude exposure. Visual performance on both NVG test charts improved over time during the ground data collection period while visual performance at altitude remained basically unchanged. In contrast, unaided low contrast visual performance was unchanged during ground level testing, but statistically improved at altitude. Comparing visual performance following exercise or non-exercise conditions, no statistical difference was found on NVG data or on unaided low contrast testing. However, statistical significance was observed in unaided high contrast data, where exercise negatively affected visual performance.

Beyond statistical consideration, clinical significance was considered in the results of this study. Clinical significance, for the purpose of this study, was a change of three or more correctly identified letters on a given chart as compared to the ground level data reference. Under all conditions, there were no clinically significant visual performance findings in this study.

Operational significance was the final consideration of the study results. While the clinical consideration of visual performance changes at 10,000 ft suggests possibly insignificant loss compared to ground level performance, a statistically significant change and trend was observed. Operational impact cannot be ruled out when considering the tightly controlled study environment with programmed physical and mental test points as opposed to the higher and more variable environment of military aviation. Further investigation is recommended.

The response to the hypoxia and acute mountain sickness symptoms questionnaires showed significantly increased rates of headache, lightheadedness, fatigue and lack of concentration at 10,000 ft. However, there was no difference in the reported symptoms in the exercising versus the non-exercising group. Since acute mountain sickness usually starts with headache, an increase of reported headache at 10,000 ft could be a sign of imminent mild acute mountain sickness. However, the increase was not more pronounced with the moderate exercise prescribed in this study and exercise is known to provoke acute mountain sickness. Thus, if mild symptoms of acute mountain sickness were imminent, the intensity of the exercise used in this study may have been too low to have had an impact.

In conclusion, the findings in this study with mild hypoxia at 10,000 feet (3048 m) equivalent altitude for 12 hours indicated a minimal influence of low-grade hypoxia on cognitive performance and NVG vision. No significant negative impact on cognitive function was found, but minor negative effects on night vision goggle performance under operational lighting (starlight) conditions were found. The altitude exposure did not negatively affect unaided night vision performance under mesopic (twilight) lighting. There was a slight increase in self-reported symptoms of headache, fatigue and lack of concentration. The increased reports of headache could possibly represent an imminent mild onset of acute mountain sickness.

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Appendix A: Pulse Oximetry (SaO_2)—Descriptive Statistics (means and standard deviations) and ANOVA Results

Altitude	Exercise Group	Time										
		1hr	2hr	3hr	4hr	5hr	6hr	7hr	8hr	9hr	10hr	11hr
10,000ft	Exer	89.9 1.9	90.7 1.9	89.7 1.8	90.7 1.5	89.7 2.5	90.0 1.7	90.1 1.9	90.3 2.2	89.6 3.9	89.1 3.9	89.3 3.7
	no exer	89.9 2.4	89.9 2.6	89.5 2.4	90.3 3.1	90.5 3.3	90.4 2.4	90.5 3.5	90.0 2.4	90.5 3.2	89.4 3.8	89.9 3.9
	Overall	89.9 2.2	90.3 2.3	89.6 2.1	90.5 2.4	90.1 2.9	90.2 2.1	90.3 2.8	90.2 2.3	90.0 3.6	89.2 3.8	89.6 3.7
ground	Exer	96.4 3.3	95.9 3.3	96.8 1.0	96.9 2.1	96.7 1.0	97.1 1.2	97.1 1.4	97.1 1.1	97.1 1.1	96.5 1.4	96.9 1.0
	no exer	96.4 1.9	97.2 1.6	96.9 2.0	96.9 1.8	96.9 1.6	97.1 1.5	97.3 1.8	97.7 1.2	97.3 1.5	97.1 1.2	97.3 1.5
	Overall	96.4 2.6	96.6 2.6	96.8 1.5	96.9 1.9	96.8 1.3	97.1 1.3	97.2 1.6	97.4 1.1	97.2 1.3	96.8 1.3	97.1 1.3

ANOVA Results				
Test	MSE	df	F	p
exercise	39.89	1,28	.23	.639
altitude	13.40	1,28	595.35	**<.001**
ex * alt	13.40	1,28	1.105	.776
time	4.93	8,211[h]	1.09	.37
ex * tm	4.93	8,211 [h]	.26	.97
alt * tm	3.83	8,231 [h]	.91	.512
e * a * t	3.83	8,231 [h]	.70	.699

Notes: 1. The entries in each cell are the mean (top) and corresponding standard deviation (bottom).
2. [h] indicates that the Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.

Appendix B: SaO_2 and HR During Exercise—Descriptive Statistics (means and standard deviations) and ANOVA Results

Variable	Altitude	Time					ANOVA Results				
		2hr	4hr	6hr	8hr	10hr	Test	MSE	df	F	p
Average Heart Rate	10,000ft	133.0	137.1	135.7	134.0	135.2	Altitude	40.36	1,14	3.71	.075
		4.6	4.8	5.2	6.2	6.6	Time	26.26	$2,33^{h}$	3.31	**.042**
	ground	130.6	132.6	133.6	133.5	134.7	Alt * Tim	16.45	$3,43^{h}$	1.61	.200
		9.9	5.7	5.5	4.2	6.0					
Average SaO_2	10,000ft	87.3	86.6	87.0	86.6	86.4	Altitude	31.26	1,14	101.17	**<.001**
		3.1	3.2	3.7	4.1	3.8	Time	2.71	$2,29^{h}$	1.00	**<.001**
	ground	96.0	96.2	95.9	95.8	95.8	Alt * Tim	4.14	$3,38^{h}$	.41	.729
		1.8	1.6	2.2	3.4	2.5					
Max Heart Rate	10,000ft	138.6	142.4	140.2	140.0	141.5	Altitude	51.15	1,14	3.09	.101
		4.8	5.9	6.3	6.2	5.5	Time	13.82	4,56	2.81	**.034**
	ground	137.3	137.3	138.5	138.6	140.7	Alt * Tim	4.14	$3,38^{h}$	.41	.729
		10.8	6.1	6.7	6.1	7.9					
Min SaO_2	10,000ft	85.1	84.4	84.9	84.3	83.9	Altitude	40.07	1,14	88.18	**<.001**
		3.6	3.6	4.2	4.3	4.3	Time	7.99	$2,27^{h}$	.24	.786
	ground	93.7	94.5	94.2	94.5	94.3	Alt * Tim	11.83	$3,40^{h}$	.45	.713
		4.5	2.6	3.0	4.8	3.6					

Notes: 1. The entries in each cell are the mean (top) and corresponding standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.

Appendix C: Cognitive Performance--Descriptive Statistics (baseline means & std dev, and mean changes & std dev at each time) and ANOVA Results

Test	Variable	Altitude	Exercise Group	base line	Change from baseline at time: 2h	4h	6h	8h	10h	11h	post
CPT	Accuracy	10,000ft	exer	95.1 3.8	0.3 4.2	0.0 3.8	0.7 2.7	0.6 2.9	1.3 3.8	0.1 3.7	-0.5 2.8
			no exer	95.8 3.5	-0.9 2.5	0.8 2.5	-0.3 3.5	-0.2 3.3	0.5 2.4	0.5 2.8	0.7 2.8
			overall	95.5 3.6	-0.3 3.4	0.4 3.2	0.2 3.1	0.1 3.1	0.9 3.1	0.3 3.2	0.1 2.8
		ground	exer	96.1 3.1	0.4 2.0	0.4 1.8	0.1 3.6	0.2 2.7	0.2 3.3	-0.8 3.4	-1.3 2.4
			no exer	97.6 2.6	-0.8 2.8	0.8 2.1	-0.8 3.1	-0.7 2.7	0.3 2.5	-0.8 1.6	-1.6 3.9
			overall	96.8 2.9	-0.2 2.5	0.6 1.9	-0.4 3.3	-0.2 2.7	0.3 2.9	-0.8 2.6	-1.4 3.2
	MRTC	10,000ft	exer	447.0 99.5	-16.4 48.3	-28.7 44.7	-23.4 52.2	-31.5 60.1	-41.4 53.4	-45.6 56.8	-56.8 57.3
			no exer	489.8 67.0	10.7 31.6	5.7 49.1	8.9 49.6	6.3 48.1	-19.8 46.2	-8.3 49.4	-25.0 46.7
			overall	469.1 85.5	-2.4 42.1	-10.9 49.4	-6.7 52.6	-11.9 56.6	-30.2 50.1	-26.3 55.5	-40.4 53.6
		ground	exer	419.1 53.8	-6.5 28.4	-1.4 42.9	2.8 44.1	-9.5 44.6	-20.1 33.4	-29.2 41.9	-42.8 25.7
			no exer	508.7 60.5	5.0 39.8	-18.6 26.2	-17.1 28.2	-8.2 35.0	-35.5 35.1	-37.0 34.8	-52.1 40.7
			overall	465.5 72.5	-0.6 34.7	-10.3 35.7	-7.5 37.4	-8.8 39.2	-28.1 34.5	-33.2 37.9	-47.6 34.0
	Thruput	10,000ft	exer	133.4 26.4	3.2 7.8	6.8 13.8	4.8 12.3	7.6 14.3	12.0 12.9	12.0 14.0	15.1 14.3
			no exer	119.5 15.4	-4.3 9.8	-0.1 11.4	-2.0 14.7	-1.8 12.8	6.3 12.0	1.9 11.3	7.1 12.4
			overall	126.2 22.2	-0.7 9.5	3.2 12.8	1.3 13.8	2.7 14.1	9.1 12.5	6.8 13.5	10.9 13.7
		ground	exer	139.6 16.6	2.4 11.6	0.5 14.8	-0.9 14.9	3.9 15.8	6.7 9.5	9.1 13.4	13.6 9.0
			no exer	116.8 15.0	-2.5 11.0	5.2 9.2	2.6 9.2	1.1 8.9	8.6 9.0	7.8 8.1	11.6 10.5
			overall	127.8 19.3	-0.1 11.4	2.9 12.2	0.9 12.1	2.4 12.6	7.7 9.1	8.5 10.8	12.5 9.7
Grammatical Reasoning	Accuracy	10,000ft	exer	90.8 6.4	0.1 4.3	0.8 4.4	1.1 4.2	1.8 4.3	2.4 4.8	-0.7 5.6	0.0 5.2
			no exer	88.1 10.4	-0.3 7.3	0.8 7.4	0.7 8.0	1.8 5.6	2.2 4.8	-0.8 9.6	1.9 4.6
			overall	89.4 8.6	-0.1 5.9	0.8 6.0	0.9 6.3	1.8 4.9	2.3 4.7	-0.8 7.7	1.0 4.9
		ground	exer	91.1 4.8	1.3 8.9	2.4 5.8	0.7 5.0	1.3 5.7	2.5 4.9	-0.7 7.8	1.2 5.7
			no exer	89.6 10.6	-1.7 5.3	2.4 5.0	0.3 6.2	-0.4 6.7	1.9 3.2	0.8 4.3	-1.3 4.8
			overall	90.3 8.1	-0.2 7.4	2.4 5.4	0.5 5.5	0.4 6.2	2.2 4.1	0.1 6.2	0.0 5.3

Test	Variable	ANOVA Results: Test	MSE	df	F	p
CPT	Accuracy	exercise	30.25	1,27	.28	.602
		altitude	23.57	1,27	1.14	.296
		ex * alt	23.57	1,27	.05	.832
		time	5.00	7,189	1.93	.067
		ex * tm	5.00	7,189	1.37	.219
		alt * tm	5.72	$6,166^h$	1.03	.411
		e * a * t	5.72	$6,166^h$	.31	.935
	MRTC	exercise	8590.22	1,27	1.44	.240
		altitude	7590.84	1,27	.002	.968
		ex * alt	7590.84	1,27	4.64	**.040**
		time	876.30	$6,163^h$	19.20	**<.001**
		ex * tm	876.30	$6,163^h$	1.00	.429
		alt * tm	1305.99	$4,106^h$	.30	.873
		e * a * t	1305.99	$4,106^h$	1.63	.172
	Thruput	exercise	557.22	1,27	2.47	.128
		altitude	551.02	1,27	.00	.971
		ex * alt	551.02	1,27	2.34	.138
		time	77.42	$5,164^h$	17.16	**<.001**
		ex * tm	77.42	$5,164^h$	1.39	.220
		alt * tm	58.59	7,189	.28	.961
		e * a * t	58.59	7,189	.92	.494
Grammatical Reasoning	Accuracy	exercise	140.01	1,28	.11	.740
		altitude	107.66	1,28	.01	.930
		ex * alt	107.66	1,28	.25	.622
		time	19.52	$5,168^h$	2.96	**.009**
		ex * tm	19.52	$5,168^h$	.43	.859
		alt * tm	19.07	$6,178^h$	.75	.615
		e * a * t	19.07	$6,178^h$	.77	.602

Appendix C (page 2)

Test	Variable	Altitude	Exercise Group	base line	2h	4h	6h	8h	10h	11h	post	Test	MSE	df	F	p
					Change from baseline at time:							ANOVA Results				
Grammatical Reasoning (continued)	MRTC	10,000ft	exer	4824.3	-105.0	-362.4	-223.0	-458.2	-487.9	-506.7	-726.1					
				1515.9	452.2	538.2	526.8	482.5	659.1	644.8	927.6					
			no exer	5531.9	-193.1	-442.6	-426.6	-499.2	-557.9	-602.5	-783.1	exercise	2606552.24	1,28	.07	.788
				1283.4	654.8	657.0	680.2	755.4	668.3	768.8	761.8	altitude	1421449.76	1,28	8.30	**.008**
			overall	5178.1	-149.1	-402.5*	-324.8*	-478.7*	-522.9*	-554.6*	-754.6	ex * alt	1421449.76	1,28	.13	.719
				1426.2	554.7	591.5	606.6	623.1	653.1	698.8	834.5	time	422694.66	4,113^{h}	9.81	**<.001**
		ground	exer	4531.5	-104.8	23.6	106.9	-75.7	-120.5	-109.5	-396.5	ex * tm	422694.66	4,113^{h}	.30	.880
				1332.7	732.6	362.9	752.6	911.9	897.7	1181.4	897.4	alt * tm	262788.78	5,151^{h}	2.18	.055
			no exer	5100.2	79.7	188.1	96.3	-46.2	-273.8	-148.8	-575.0	e * a * t	262788.78	5,151^{h}	.40	.861
				1223.7	488.5	629.5	643.8	647.4	699.4	491.0	891.1					
			overall	4815.9	-12.5	105.9*	101.6*	-60.9*	-197.2*	-129.1*	-485.7					
				1289.9	619.0	511.7	688.2	777.2	794.5	889.2	883.4					
	Thruput	10,000ft	exer	12.1	0.3	0.8	0.7	1.4	1.3	1.1	1.9					
				3.2	1.1	1.6	2.1	1.6	1.1	1.9	2.0					
			no exer	10.1	0.3	0.9	0.9	1.2	1.5	1.0	1.9	exercise	18.61	1,28	.32	.575
				2.8	1.6	1.9	2.1	1.9	1.5	1.4	1.5	altitude	9.65	1,28	3.53	.071
			overall	11.1	0.3	0.8	0.8	1.3	1.4	1.0	1.9	ex * alt	9.65	1,28	.41	.528
				3.1	1.4	1.7	2.1	1.7	1.3	1.7	1.7	time	3.23	4,115^{h}	10.39	**<.001**
		ground	exer	12.7	0.3	0.2	-0.2	0.1	0.5	-0.3	1.1	ex * tm	3.23	4,115^{h}	.60	.666
				3.0	1.2	1.3	2.3	2.2	2.2	2.3	1.8	alt * tm	3.53	4,112^{h}	.87	.486
			no exer	11.1	-0.2	0.1	0.1	0.7	1.5	0.5	2.1	e * a * t	3.53	4,112^{h}	.57	.684
				3.1	1.1	1.5	1.9	2.9	3.5	1.5	3.8					
			overall	11.9	0.1	0.2	-0.1	0.4	1.0	0.1	1.6					
				3.1	1.1	1.4	2.1	2.5	2.9	1.9	2.9					
Match to Sample	Accuracy	10,000ft	exer	95.1	2.1	1.8	2.1	0.3	0.9	1.5	2.0					
				4.8	4.6	6.2	4.6	4.4	4.4	3.8	5.8					
			no exer	96.2	2.7	1.4	0.5	1.4	0.6	0.3	1.4	exercise	83.10	1,28	.34	.567
				4.7	3.7	5.0	5.4	4.0	4.4	5.4	5.7	altitude	73.76	1,28	2.84	.103
			overall	95.6	2.4	1.6	1.3	0.9	0.8	0.9	1.7	ex * alt	73.76	1,28	.07	.792
				4.7	4.1	5.5	5.0	4.2	4.3	4.6	5.6	time	9.63	6,171^{h}	.62	.719
		ground	exer	96.6	-0.3	-0.4	0.8	0.0	0.6	1.9	-1.0	ex * tm	9.63	6,171^{h}	1.60	.148
				4.0	4.8	3.4	5.0	4.3	4.7	3.8	4.7	alt * tm	10.92	7,196	1.65	.123
			no exer	97.9	-0.6	-1.4	-1.5	0.1	0.1	-0.5	0.1	e * a * t	10.92	7,196	.28	.960
				3.4	2.9	2.7	5.4	3.9	4.5	4.5	3.8					
			overall	97.2	-0.4	-0.9	-0.3	0.0	0.3	0.7	-0.4					
				3.7	3.9	3.1	5.2	4.0	4.6	4.3	4.2					
	MRTC	10,000ft	exer	903.1	-59.9	-87.0	-91.0	-75.0	-106.7	-135.5	-128.7					
				300.9	136.2	118.2	161.1	166.6	148.7	147.8	205.5					
			no exer	999.3	33.0	-9.6	-17.4	3.9	-51.9	-85.2	-106.9	exercise	93350.08	1,28	3.09	.090
				290.4	133.4	156.9	147.2	235.4	153.8	186.2	185.3	altitude	97106.94	1,28	.02	.892
			overall	951.2	-13.4	-48.3	-54.2	-35.6	-79.3	-110.4	-117.8	ex * alt	97106.94	1,28	.06	.803
				294.6	140.6	142.1	156.2	204.4	151.3	167.2	192.6	time	16502.44	7,196	7.11	**<.001**
		ground	exer	845.5	-48.9	-49.8	-22.9	-81.8	-59.3	-164.1	-168.5	ex * tm	16502.44	7,196	.97	.453
				377.2	103.9	184.9	139.8	157.7	136.8	159.1	191.9	alt * tm	11744.82	7,196	1.21	.301
			no exer	1030.9	2.7	-42.3	15.1	-48.9	-43.0	2.0	-145.9	e * a * t	11744.82	7,196	1.06	.392
				203.7	172.2	146.1	166.8	204.9	243.4	154.5	132.6					
			overall	938.2	-23.1	-46.0	-3.9	-65.4	-51.1	-81.0	-157.2					
				312.5	142.2	163.8	152.4	180.4	194.2	175.7	162.5					

Appendix C (page 3)

Test	Variable	Altitude	Exercise Group	base line	Change from baseline at time: 2h	4h	6h	8h	10h	11h	post	ANOVA Results: Test	MSE	df	F	p
Match to Sample (Continued)	Thruput	10,000ft	exer	68.6	12.6	14.7	19.6	13.5	20.8	22.2	33.6					
				18.5	20.6	21.7	30.0	26.4	48.5	51.2	66.1					
			no exer	63.7	0.9	4.5	4.6	6.4	8.3	10.9	15.8	exercise	4367.58	1,28	2.07	.161
				26.0	11.5	11.5	19.0	25.6	19.9	26.7	28.6	altitude	1559.60	1,28	2.12	.156
			overall	66.2	6.7	9.6	12.1	9.9	14.5	16.6	24.7	ex * alt	1559.60	1,28	.308	.583
				22.3	17.4	17.8	25.9	25.8	37.0	40.5	50.9	time	1190.63	2,55^{h}	7.92	**.001**
		ground	exer	82.0	3.1	5.2	3.7	4.7	11.6	28.9	21.8	ex * tm	1190.63	2,55^{h}	1.72	.189
				36.2	10.4	18.0	18.4	12.4	26.3	31.7	27.5	alt * tm	345.97	4,108^{h}	.81	.518
			no exer	59.3	0.2	2.4	-1.3	4.8	6.8	-0.6	13.0	e * a * t	345.97	4,108^{h}	1.75	.146
				16.0	8.9	9.0	8.6	8.6	13.5	9.0	15.2					
			overall	70.6	1.7	3.8	1.2	4.7	9.2	14.2	17.4					
				29.8	9.6	14.1	14.4	10.5	20.7	27.4	22.3					
Math	Accuracy	10,000ft	exer	88.8	5.8	3.4	4.8	6.0	5.9	6.1	4.4					
				22.3	22.1	22.1	20.6	22.8	20.4	20.4	20.4					
			no exer	94.8	-0.4	0.7	-0.1	1.2	1.6	0.7	1.5	exercise	836.71	1,28	.40	.530
				4.4	3.7	4.0	4.6	4.0	5.9	3.4	3.4	altitude	588.43	1,28	2.21	.148
			overall	91.8	2.7	2.1	2.4	3.6	3.8	3.4	2.9	ex * alt	588.43	1,28	1.02	.322
				16.1	15.9	15.6	14.9	16.2	14.9	14.7	14.5	time	76.78	2,69^{h}	.59	.593
		ground	exer	95.5	-1.1	-1.4	-2.0	-2.1	0.3	0.1	-1.6	ex * tm	76.78	2,69^{h}	.88	.440
				3.6	4.2	5.2	4.3	4.4	3.6	3.3	3.5	alt * tm	49.05	3,82^{h}	1.74	.167
			no exer	96.2	-0.9	0.5	0.4	-1.1	-0.7	-1.3	-0.3	e * a * t	49.05	3,82^{h}	.92	.432
				3.9	4.4	2.4	3.6	4.2	3.3	4.9	3.7					
			overall	95.8	-1.0	-0.4	-0.8	-1.6	-0.2	-0.6	-0.9					
				3.7	4.2	4.1	4.0	4.2	3.5	4.2	3.6					
	MRTC	10,000ft	exer	1867.3	-180.5	-169.5	-176.0	-263.1	-216.8	-283.9	-245.0					
				674.9	223.5	344.0	362.3	297.7	266.8	375.9	435.8					
			no exer	1931.8	-33.5	-88.1	-64.0	-140.5	-136.6	-123.7	-146.1	exercise	259968.03	1,28	1.42	.244
				317.2	282.7	259.1	188.5	205.7	230.6	216.2	206.3	altitude	377547.57	1,28	1.49	.232
			overall	1899.6	-107.0	-128.8	-120.0	-201.8	-176.7	-203.8	-195.6	ex * alt	377547.57	1,28	.64	.430
				519.2	261.3	302.0	289.4	259.0	248.4	312.1	338.7	time	36486.66	5,145^{h}	7.07	**<.001**
		ground	exer	1650.3	-70.0	-66.2	-52.7	-92.0	-94.3	-37.1	-215.5	ex * tm	36486.66	5,145^{h}	.44	.829
				471.3	182.7	263.4	287.2	357.4	207.0	274.5	304.6	alt * tm	33195.49	5,144^{h}	1.73	.130
			no exer	1873.4	-77.8	-89.0	-2.1	-109.1	-54.0	-61.2	-150.8	e * a * t	33195.49	5,144^{h}	.67	.653
				342.7	157.1	157.5	179.0	198.8	162.8	220.7	340.6					
			overall	1761.8	-73.9	-77.6	-27.4	-100.5	-74.1	-49.2	-183.1					
				420.5	167.4	213.6	236.5	284.3	184.1	245.1	319.1					
	Thruput	10,000ft	exer	32.9	4.3	3.3	3.7	5.3	5.4	6.5	5.6					
				14.1	6.0	7.7	7.2	6.5	6.3	7.4	8.8					
			no exer	30.0	0.4	1.9	1.3	2.7	3.0	2.1	2.8	exercise	155.13	1,28	1.67	.207
				6.0	5.5	5.3	4.1	4.3	3.9	4.3	4.4	altitude	120.86	1,28	3.85	.060
			overall	31.5	2.4	2.6	2.5	4.0	4.2	4.3	4.2	ex * alt	120.86	1,28	1.03	.319
				10.7	6.0	6.6	5.9	5.5	5.3	6.3	7.0	time	17.97	5,151^{h}	5.58	**<.001**
		ground	exer	37.3	0.3	0.7	0.6	0.9	2.4	0.7	4.7	ex * tm	17.97	5,151^{h}	1.05	.391
				10.8	4.8	5.5	6.4	7.7	7.0	6.6	7.8	alt * tm	12.90	6,166^{h}	2.10	.056
			no exer	31.6	0.9	1.6	0.1	1.4	0.5	0.1	2.1	e * a * t	12.90	6,166^{h}	.99	.434
				5.8	2.9	2.7	2.8	3.7	3.5	3.0	5.0					
			overall	34.4	0.6	1.1	0.4	1.2	1.4	0.4	3.4					
				9.0	3.9	4.3	4.9	6.0	5.5	5.0	6.6					

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Test	Variable	Altitude	Exercise Group	base line	2h	4h	6h	8h	10h	11h	post	Test	MSE	df	F	p
					Change from baseline at time:							ANOVA Results				
Tower of Hanoi	Excess Moves	10,000ft	exer	2.9 2.8	-1.5 1.4	-1.3 2.7	-1.6 2.2	-1.2 1.4	-1.4 1.7	-0.8 1.7	-1.1 1.9	exercise	12.00	1,28	.93	.344
			no exer	2.5 1.6	-0.4 2.1	-1.1 1.6	-0.7 1.0	-1.3 1.4	-0.8 1.4	-0.7 2.0	-0.9 1.4	altitude	12.90	1,28	.27	.607
			overall	2.7 2.2	-0.9 1.8	-1.2 2.2	-1.1 1.7	-1.3 1.4	-1.1 1.6	-0.8 1.8	-1.0 1.7	ex * alt	12.90	1,28	.04	.850
		ground	exer	2.4 1.7	-0.7 1.9	-1.3 2.1	-0.7 2.0	-0.6 2.1	-1.7 1.9	-0.7 1.8	-1.1 1.6	time	1.61	$6,176^h$	5.72	**<.001**
			no exer	2.3 1.3	-0.9 1.4	-0.9 1.6	-1.1 1.5	-0.7 1.5	-0.6 2.1	-0.4 1.2	-0.5 2.0	ex * tm	1.61	$6,176^h$	.91	.492
			overall	2.4 1.5	-0.8 1.6	-1.1 1.8	-0.9 1.7	-0.6 1.8	-1.2 2.0	-0.6 1.5	-0.8 1.8	alt * tm	1.28	7,196	.56	.792
												e * a * t	1.28	7,196	1.55	.154
	MRT	10,000ft	exer	1108.4 317.3	96.7 248.3	-48.2 170.3	117.7 189.7	-24.7 172.6	44.0 230.8	-15.4 158.4	-113.0 180.1	exercise	373575.66	1,28	.01	.918
			no exer	1566.7 464.7	-78.7 278.5	-101.2 398.1	100.7 334.7	-78.3 315.8	-73.8 371.1	-17.2 372.5	-155.8 247.9	altitude	242758.66	1,28	.59	.448
			overall	1337.5 455.2	9.0 274.2	-74.7 302.1	109.2 267.4	-51.5 251.6	-14.9 309.5	-16.3 281.3	-134.4 214.0	ex * alt	242758.66	1,28	1.99	.169
		ground	exer	1188.6 305.7	6.5 431.9	-147.6 191.1	-79.7 280.3	-107.8 210.9	-113.9 207.1	-120.5 238.3	-164.4 217.8	time	75518.12	$5,150^h$	3.95	**.002**
			no exer	1500.3 321.1	22.8 354.2	-25.0 421.3	47.8 619.1	-28.8 327.8	-9.5 281.7	-2.0 346.9	-179.1 501.1	ex * tm	75518.12	$5,150^h$	.55	.752
			overall	1344.5 346.4	14.7 388.2	-86.3 327.4	-15.9 476.6	-68.3 273.8	-61.7 248.7	-61.2 298.6	-171.7 379.7	alt * tm	58168.02	$6,180^h$	.49	.831
												e * a * t	58168.02	$6,180^h$	.42	.877

Notes:

1. The entries in each cell are the mean (top) and corresponding standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.
3. * indicates a significant (p<.05) difference between the change from baseline at ground level and the change from baseline at 10,000ft.

Appendix D: Vision Tests--Descriptive Statistics
(baseline means & std dev, and mean changes & std dev at each time,) and ANOVA Results

Test	Altitude	Exercise Group	Base line	Change from baseline at time:						ANOVA Results				
				1h	3h	5h	7h	9h	11h	Test	MSE	df	F	p
Bailey-Lovie (NVG)	10,000ft	exer	37.8	-1.2	-1.5	-1.9	-0.6	-1.9	-1.9					
			5.1	6.3	4.6	6.0	4.4	5.9	4.5					
		no exer	36.3	-3.6	-1.9	0.7	0.7	0.1	-0.9	exercise	89.37	1,27	1.32	.260
			3.6	4.7	3.7	2.7	3.5	3.3	6.1	altitude	80.00	1,27	6.79	**.015**
		overall	37.0	-2.4	-1.7	-0.6*	0.0	-0.9*	-1.4*	ex * alt	80.00	1,27	.28	.602
			4.3	5.6	4.1	4.7	3.9	4.8	5.3	time	11.20	6,162	2.92	**.010**
	ground	exer	37.1	-0.8	-0.4	0.6	0.1	1.1	3.1	ex * tm	11.20	6,162	1.94	.077
			4.1	4.8	3.2	3.4	4.2	5.3	3.6	alt * tm	12.33	6,162	2.37	**.032**
		no exer	34.3	1.0	1.7	4.0	1.9	3.4	2.6	e * a * t	12.33	6,162	1.00	.427
			5.6	4.8	8.3	6.2	6.2	6.0	6.0					
		overall	35.7	0.1	0.7	2.3*	1.0	2.3*	2.9*					
			5.0	4.8	6.4	5.2	5.3	5.7	4.9					
Pelli_Robson (NVG)	10,000ft	exer	20.2	0.4	-0.3	-0.4	0.5	0.2	0.3					
			2.4	2.6	2.8	3.6	2.2	2.9	2.6					
		no exer	21.5	-1.7	-0.6	-0.2	-0.5	-0.1	-0.1	exercise	21.61	1,27	.10	.750
			2.3	3.0	1.9	2.5	3.0	2.4	2.3	altitude	19.90	1,27	6.93	**.014**
		overall	20.9	-0.7*	-0.4*	-0.3	0.0	0.1*	0.1*	ex * alt	19.90	1,27	.82	.373
			2.4	3.0	2.3	3.0	2.7	2.6	2.4	time	2.60	6,162	2.75	**.014**
	ground	exer	19.8	0.6	0.9	1.1	0.8	1.2	1.6	ex * tm	2.60	6,162	.57	.753
			2.2	1.8	2.0	2.1	2.4	1.6	1.6	alt * tm	2.89	6,162	1.52	.176
		no exer	20.3	1.0	0.8	1.2	1.3	1.5	2.0	e * a * t	2.89	6,162	1.02	.414
			1.9	2.0	2.5	3.0	3.1	2.5	2.1					
		overall	20.0	0.8*	0.8*	1.1	1.0	1.4*	1.8*					
			2.0	1.9	2.3	2.6	2.7	2.1	1.8					
High Contrast unaided	10,000ft	exer	43.1	-1.6	-0.7	-1.6	-1.7	-1.0	-2.4					
			3.5	3.1	2.5	4.5	3.5	4.9	4.7					
		no exer	41.1	1.5	0.8	1.2	1.0	2.7	0.4	exercise	44.59	1,27	5.66	**.025**
			5.9	3.0	1.6	2.3	2.4	3.8	2.3	altitude	36.66	1,27	.37	.549
		overall	42.0	0.0	0.1	-0.1	-0.3	0.9	-0.9	ex * alt	36.66	1,27	1.74	.198
			4.9	3.4	2.2	3.7	3.3	4.7	3.9	time	5.54	6,162	1.98	.072
	ground	exer	43.8	-0.7	-1.9	-0.3	-1.8	-0.4	-0.9	ex * tm	5.54	6,162	1.38	.224
			4.5	3.0	3.9	3.9	4.0	3.5	4.4	alt * tm	4.77	6,162	.98	.442
		no exer	42.3	-0.4	-0.2	0.5	-0.3	0.3	-0.4	e * a * t	4.77	6,162	1.26	.277
			6.3	3.0	3.8	3.0	3.1	3.5	3.4					
		overall	43.0	-0.6	-1.0	0.1	-1.0	0.0	-0.6					
			5.5	2.9	3.9	3.4	3.6	3.5	3.9					
Low Contrast Unaided	10,000ft	exer	23.4	0.7	1.2	0.3	1.9	1.4	0.4					
			5.6	2.8	2.4	3.4	2.0	5.9	3.2					
		no exer	22.9	1.3	0.5	0.7	1.5	1.9	0.7	exercise	29.36	1,27	.11	.738
			6.6	4.0	2.7	3.8	2.7	2.9	3.7	altitude	27.89	1,27	4.45	**.044**
		overall	23.1	1.0	0.8	0.5	1.7*	1.7	0.6	ex * alt	27.89	1,27	.01	.914
			6.0	3.4	2.5	3.6	2.4	4.5	3.4	time	4.41	6,162	1.60	.151
	ground	exer	24.8	0.6	0.1	-1.1	-0.9	0.1	-1.1	ex * tm	4.41	6,162	.69	.662
			5.8	2.3	3.2	2.5	3.1	2.8	2.9	alt * tm	4.69	6,162	1.79	.105
		no exer	23.2	-0.9	0.7	0.3	-0.4	-0.1	-0.2	e * a * t	4.69	6,162	1.08	.375
			7.7	2.6	1.7	3.1	2.2	3.0	1.8					
		overall	24.0	-0.1	0.4	-0.4	-0.6*	0.0	-0.6					
			6.8	2.5	2.5	2.8	2.6	2.8	2.4					

Notes: 1. The entries in each cell are the mean (top) and corresponding standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.