MULTI-TASK PERFORMANCE AT SEA-LEVEL AND HIGH ALTITUDE

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ABSTRACT

Warfighter exposure to high terrestrial altitude continues to be a reality for the modern fighting force. Understanding the negative effects of altitude on cognitive performance is essential as the cognitive demands of many warfighting tasks are becoming increasingly complex. To date, little research has investigated the performance of multiple cognitive tasks in a high altitude environment. The work reported here was designed to investigate the performance of Soldiers on a multi-task cognitive assessment at sea-level and high altitude (4300m) both before (hypobaric chamber) and after (terrestrial altitude) living for six days at moderate altitude (2200m). Results indicate that multi-task performance declined during initial**,** unacclimatized high altitude exposure compared to sea-level. In contrast, performance at high altitude after staging did not differ from sea-level. While these results suggest that the stay at moderate altitude produced acclimatization which worked to sustain cognitive performance, the effects of task learning and individual differences in response to altitude are also discussed.

1. INTRODUCTION

Rapid deployment of Warfighters to areas of moderate to high altitude to conduct military operations is currently being done in the support of the Global War on Terrorism in Afghanistan and northern Iraq. Enemy use of this mountainous terrain lessens U.S. military technological superiority by limiting the use of air support and crew-served combat vehicles and places the burden of combat on dismounted Warfighters. Insertion of an unacclimatized fighting unit into a high altitude environment – as is often done by airlift from low to high altitude – may compromise mission success by causing acute mountain sickness (AMS) and impairing physical and cognitive performance. The negative impact of rapid deployment to altitude on fighting capabilities has been documented by after-action reports published by the Center for Army Lessons Learned. For example, during a combat operation in Afghanistan at elevations between 2400m and 3650m, approximately 12% of medical evacuations and hospital admissions were due to severe AMS. It was not reported how many Warfighters had more moderate AMS or experienced declines in cognitive performance.

1.1 Altitude Exposure and Cognitive Performance

Ascent to high altitude results in reduced oxygenation of the blood (hypoxemia) as well as neurological changes, including increased cerebral blood flow and hypoxia in the hippocampal and limbic systems (Virués-Ortega et al., 2004; Finnoff, 2008). Whether general hypoxemia or hypoxia specific to certain neural tissues produce greater effects on cognitive performance is not known, but it is widely accepted that altitude exposure can adversely affect cognitive performance. Altitude effects on cognition differ depending upon the type of task studied and the elevation (Banderet & Burse, 1991), but are commonly seen at elevations greater than 3000m (Banderet & Shukitt-Hale, 2002). This decline in performance has been seen in several domains of cognition including logical reasoning and directed attention (Crowley et al., 1992), short term memory and learning (Regard et al., 1991), arithmetic (Jobe et al., 1991), and reaction time to both visual and auditory stimuli (Virués-Ortega et al 2004).

While it is generally accepted that complex tasks are affected more than simple tasks (Banderet & Shukitt-Hale, 2002), very little empirical evaluation of this idea has been conducted. One study by Bouquet et al. (1999) utilized a simple psychomotor task requiring hand-eye coordination and two more complex variations of the task requiring participants to match colors and abstract symbols in addition to the hand-eye coordination piece. Altitude exposures from 4350m to 8848m showed not only a decline in both simple and complex task performance, but also a greater difference in performance of the complex tasks as compared to the simple task. While this study provided evidence of the susceptibility of complex task performance to altitude effects, what has not been studied is what happens to the performance of more complex cognitive tasks, a situation very common to the modern Warfighter.

1.2 Multi-task Performance

Cognitive demands in everyday military tasks are varied and often require attention to multiple tasks, weighing of risks, and decision-making. These

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information-processing requirements are being pushed down to the lowest level possible such that relatively junior Warfighters may need to make timely decisions regarding their life or that of their teammates. The ability to consider alternatives, evaluate risk and make decisions must often be done while paying attention to a steady flow of incoming information. In fact, the ability to attend to multiple tasks and/or multiple sources of information (i.e. visual, auditory) is essential to the completion of many military jobs, including those undertaken during combat operations. Despite the prevalence of multi-task demands in the military operational environment, little is known about the effect of high altitude on this type of cognitive performance.

One study (Terry, 2002) has been conducted using a multi-task scenario and exposure to simulated moderate (3048m) and high altitude (4267m). The author found that performance at 3048m exceeded that of performance at sea-level and at 4267m, with no observed decline in performance at high altitude relative to sea-level. Although the author conducted a comparison to assess order effects, volunteers were given only one practice period with the multi-task test prior to their assessments at altitude which suggests that these unexpected results could be influenced by a learning effect. To date, there have been no other studies published testing the effects of altitude exposure on dual- or multi-task performance.

1.3 Purpose of the Study

Multi-task performance at sea-level and high altitude was assessed as part of a larger study designed to determine the effectiveness of six days of exposure to a moderate altitude (2200m) in minimizing AMS symptoms and impairments in physical and cognitive performance during a subsequent five day exposure to high altitude (4300m). The primary interest in the cognitive aspect of this study was to examine multi-task performance at sea-level and high altitude, prior to and after acclimatization at the moderate altitude.

2. METHODS

2.1 Volunteers

Eleven male Soldiers volunteered to participate in this study. All volunteers provided verbal and written informed consent after being fully informed of the nature of the study and its possible risks and benefits. Prior to this study, all volunteers had been living at low altitudes (< 1000m) for at least 3 months. The study was approved by the institutional review boards of the US Army Research Institute of Environmental Medicine (USARIEM), the US Army Medical Research and Material Command, and the US Air Force Academy (AFA).

2.2 Multi-task Scenario

The multi-task assessment test (SynWin, Activity Research Services) was installed on individual laptop computers. The test was used with headphones and a computer mouse. This test requires participants to attend to four tasks simultaneously, thus providing a measure of participants' ability to divide attention while maintaining performance across multiple tasks. Each task appears in a separate quadrant of the computer monitor and a total score is displayed in the center of the screen. Test duration was 15 minutes for all practice and test sessions.

A self-paced arithmetic (addition of two 3- or 4-digit numbers) task is shown on one screen quadrant and provides points for every correct answer submitted and subtracts points for every incorrect answer. No points are earned or lost if no problems are attempted. The other three quadrants contain a memory task, a visual monitoring task, and an auditory detection task; each of which requires responses in timed intervals. In the memory task, the volunteer is shown a brief display of a set of six letters. Once that set disappears, single letters intermittently appear in that same quadrant. Based on memory, the participant must choose either a "yes" or "no" response to each letter to indicate whether or not that particular letter was in the original set of six. Points are awarded for correct responses, subtracted for incorrect responses, and subtracted when individuals peek at the original letter string. In the visual monitoring quadrant, volunteers must prevent a moving pointer (in the form of a fuel gauge) from reaching "empty". Every time the volunteer clicks the gauge, the pointer returns to the "full" position and points are earned. Points are subtracted when the gauge reaches "empty" without being reset. The auditory detection task requires the participant to correctly recognize a high tone, and then respond with a mouse click on a button on the screen. Low tones do not require a response. Correct responses to the target sound earn points. Points are deducted for incorrect responses: failing to respond to the target tone or responding to the incorrect tone.

2.3 Environmental Conditions and Facilities

All training and sea-level testing occurred in laboratory rooms at USARIEM. The first high altitude exposure occurred in the environmentally controlled hypobaric chamber at USARIEM (simulating a pressure altitude of 4060m, the expected summertime altitude equivalent of Pikes Peak). This exposure period provided the test of cognitive performance prior to staging. The moderate altitude staging and refresher training took place in the Human Performance Laboratory at the AFA, Colorado Springs, CO (2200m). The final high altitude exposure occurred at the USARIEM laboratory at the summit of Pikes Peak, Colorado Springs, CO (4300m), directly following the staging period. For terminology consistency, 4300m will be used to reflect the high altitude in this study.

2.4 Procedures and Testing Schedule

At sea-level, participants practiced the multi-task scenario to gain familiarity with the task and reduce variability in performance. In the first training session, participants were shown the individual tasks comprising the multi-task scenario and were instructed to familiarize themselves with the types of stimuli and responses that were required for successful performance of each task. Over a two-week period, participants practiced the multi-task scenario 10 times (2 times on 5 different days). Approximately 5 days later, participants had the sea-level test day which required them to take the test once in the morning and once in mid-afternoon. These times corresponded to the high altitude chamber exposure (pre-staging assessment) the following day which had an eight hour total duration with multi-task assessments occurring at about 1.5 and 6.5 hours post-ascent.

After about a 5 week break, participants were flown by commercial air to the AFA facility where they had 6 additional daily training sessions (staging period). On the seventh day, participants were driven to the summit of Pikes Peak (an ascent of approximately 1.5 hours) where they were tested shortly after arriving that morning (post-staging assessment) and then twice each day (once each at mid-afternoon and evening) for four days until their departure from the summit.

2.5 Design and Analysis

Where applicable, two-way repeated measures analyses of variance (ANOVA) were conducted using altitude (sea-level, high altitude) and time of day (morning, afternoon) as independent variables. Alpha was set at .05. When necessary, Greenhouse-Geisser corrections were used. Post-hoc tests for significant interactions used paired t-tests and an alpha level of .01 due to Bonferroni correction for multiple comparisons. Any additional analyses that did not have both independent variables (altitude and time of day) used the appropriate one-way ANOVA or paired t-test.

3. RESULTS

SynWin yields an overall score based on combined performance on each of the individual tasks. Thus, simultaneous performance on each of the cognitive domains: auditory detection, visual monitoring, memory, and arithmetic, provides a single metric to evaluate multi-task performance, which is the primary dependent measure of multi-task performance in this test. In addition to this composite score, individual scores from each of the tasks were analyzed. Finally, scores reflecting the quantity and quality of participant performance on each of these tasks were chosen: number of responses (math problem attempts, visual task resets), percent correct (memory, math), and percent of hits (auditory). Although all analyses used this set of dependent variables, only significant findings will be addressed in detail here. All data are presented as mean ± standard deviation.

3.1 Pre-Staging High Altitude Performance

The two-way ANOVA analyzing sea-level and high altitude performance prior to staging produced a significant effect of altitude ($F(1, 10) = 6.07$, $p < .05$) with higher scores obtained at sea-level (2201.41 ± 409.28) than at high altitude (2053.96 ± 493.64). Auditory score performance was also higher at sea-level (333.64 ± 22.03) than high altitude (274.09 ± 22.00; $F(1, 10) = 28.01$, $p < .001$) and higher in the afternoon (335.00 ± 26.07) than in the morning [272.73 ± 20.78; $F(1, 10) = 25.44$, $p < .01$]. Auditory score was most likely driven by the percentage of hits which was also higher at sea-level (99.12 ± 1.48) than high altitude (97.44 ± 2.03, $F(1, 10) = 12.79$, $p < .01$). Figure 1 shows the significant difference between sea-level and pre-staging high altitude exposure on overall task performance.

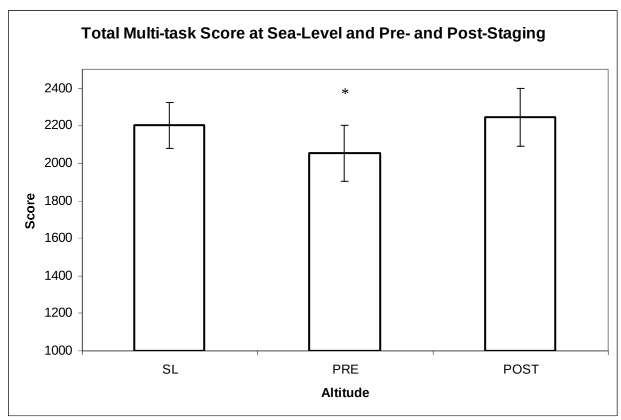

Figure 1. Overall task performance on the SynWin, collapsed over time of day. Individual analyses were performed to compare sea-level (SL) with pre-staging high altitude (PRE) and SL with post-staging high altitude (POST). *significant difference between PRE and SL performance ($p < .05$).

In addition to these results related to altitude exposure, math task scores and number of math attempts produced significant interactions between altitude and time of day. For math scores [$F(1, 10 = 9.35$, $p < .05$], post-hoc analyses showed that participants did significantly better in the afternoon (851.82 ± 317.07) than the morning (725.45 ± 262.46) when at sea-level [$t(10) = -4.54$, $p < .01$]. For the number of math problems attempted [$F(1, 10) = 15.92$, $p < .01$], not only did individuals complete more math problems in the afternoon (98.82 ± 29.14) than the morning (83.09 ± 23.75) at sea-level [$t(10) = -5.69$, $p < .001$], but they also completed more problems in the morning at pre-staging high altitude (93.00 ± 23.90) than in the morning session at sea-level [83.09 ± 23.75; $t(10) = -4.66$, $p <.01$]. These results are displayed in Figure 2.

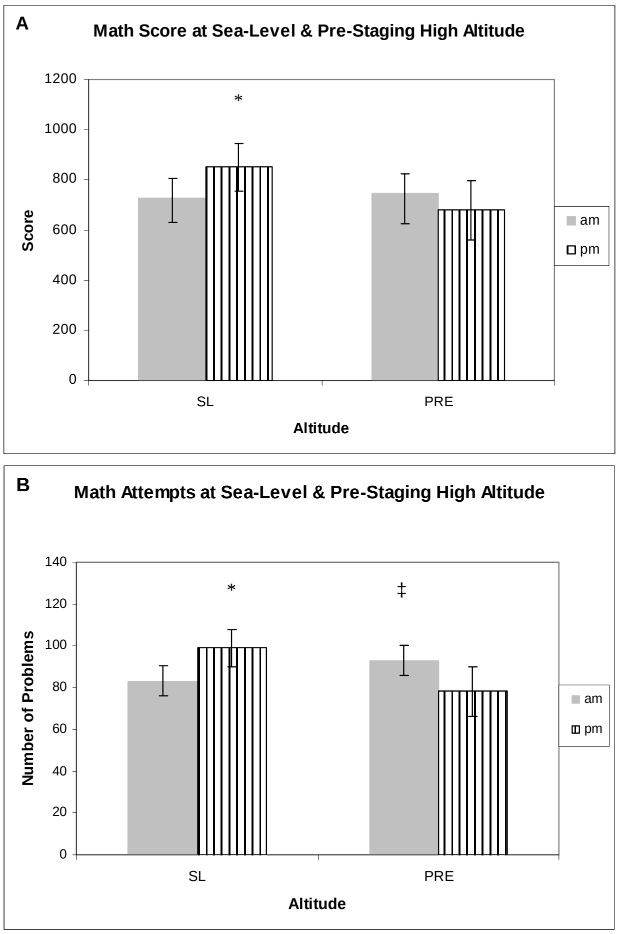

Figure 2. Total math score (panel A) and number of math problems attempted (panel B) at sea-level (SL) and pre-staging high altitude (PRE). * indicates time of day difference at SL, ‡ indicates difference between altitudes in the morning test administration ($p < .01$).

3.2 Post-Staging High Altitude Performance

In the analysis of the performance post-staging as compared to sea-level, the primary dependent variable of interest, total score, did not significantly differ from sea-level (2201.41 ± 409.28) when assessed at high altitude (2244.41 ± 508.96). Similarly, there was an absence of altitude effect for any additional variable examined. However, there were two significant interactions related to arithmetic performance: math score [$F(1,10) = 7.44$, $p < .05$] and math attempts [$F(1, 10) = 13.52$, $p < . 01$]. T-tests indicated that math scores were higher in the afternoon (851.82 ± 317.07) than the morning (725.45 ± 262.46) at sea-level [$t(10) = -4.539$, $p < .01$] and higher post-staging (970.00 ± 315.94) than at sea-level (725.45 ± 262.46) for the morning test administration [$t(10) = -4.45$, $p < .01$]. The number of math problems attempted followed the same pattern with a higher number of attempts in the afternoon (98.82 ± 29.14) than the morning (83.09 ± 23.74) at sea-level [t(10 = -5.69, $p < .001$] and the number of attempts post-staging (110.82 ± 29.02) exceeding those at sea-level (83.09 ± 23.74) for the morning test session [$t(10) = -6.00$, $p < .001$]. These results are depicted in Figure 3.

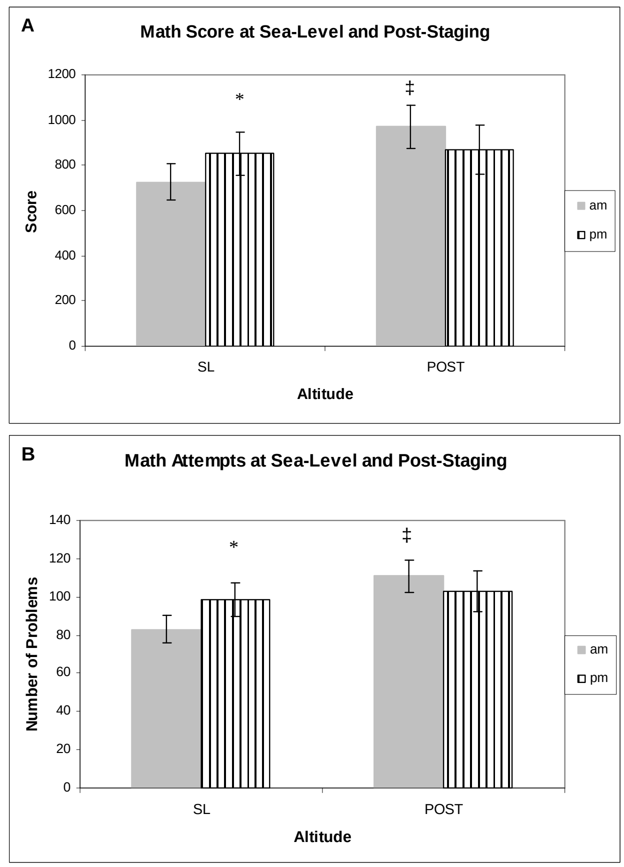

Figure 3. Total math score (panel A) and number of math problems attempted (panel B) at sea-level (SL) and at high altitude post-staging (POST). * indicates time of day difference at SL, ‡ indicates difference between altitudes in the morning test administration ($p < .01$).

3.3 Effect of Staging

In addition to assessing performance at high altitude as compared to sea-level, another study aim was to determine if staging at moderate altitude provided time for acclimatization which would have an effect on cognitive performance. Preliminary results indicated that multi-task performance varied during the six days at moderate altitude [$F(1, 10) = 8.06$, $p < .001$], with scores on day 1 (2040.36 ± 484.98) significantly lower than day 5 (2388.64 ± 477.14) and day 6 (2552.09 ± 379.27) which was also significantly higher than day 3 (2137.27 ± 498.37). Finally, data from a stable day of moderate altitude performance was chosen (day 4 did not differ from any other day) for further comparison to sea-level and post-staging high altitude performance. Staging day 4 performance did not differ from sea-level [$t(10) = .397$, $p = .70$] nor did it differ from performance at the first post-staging exposure to high altitude [$t(10) = -.76$, $p = .47$].

4. DISCUSSION

The primary finding of this study is that multi-task performance was negatively impacted by exposure to high altitude while unacclimatized. However, after moderate altitude acclimatization, there was no effect on multi-task performance relative to sea-level. This is the first study to demonstrate both a decrease in multi-task performance in unacclimatized individuals exposed to high altitude as well as a rebound of multi-task performance to sea-level values after a staging period.

4.1 Evidence of Acclimatization

The moderate altitude staging intervention was designed to provide time for altitude acclimatization. Two important measures of acclimatization are participants' self-report of Acute Mountain Sickness (AMS) symptoms using the Environmental Symptoms Questionnaire (ESQ) and arterial oxygen saturation (SaO_2) which reflects ventilatory acclimatization. Fulco et al. (2008) reported a low incidence of mild AMS at the staging elevation, and a 50% decrease in AMS incidence post-staging relative to high altitude exposure prior to staging. Additionally, SaO_2 values showed evidence of ventilatory acclimatization and physical work performance increased at the high altitude following the moderate altitude staging (Fulco et al., 2008). Taken together, these results demonstrate that moderate altitude staging produced physiological adaptations sufficient to reduce hypoxemia at subsequent high altitude exposure. While it has been shown that symptomatology and cognitive performance do not always follow the same time-course (Shukitt-Hale, Banderet, & Lieberman, 1991), the combination of these physiological and AMS data with the performance data suggest that staging was an effective strategy for reducing the negative effects of ascent to high altitude.

4.2 Implications of Individual Task Differences

In addition to overall multi-task performance, there were individual (simple) task declines before acclimatization that were not present at high altitude after moderate altitude staging. Auditory task performance as measured by task score and the percentage of hits declined at high altitude prior to staging as compared to sea-level. This result is consistent with previous research showing declines in simple task performance and attention (Banderet & Shukitt-Hale, 2002; Crowley et al., 1991); the decreased percentage of hits indicates that volunteers were missing stimuli to which they should have responded. The absence of effects for both the visual task and short term memory performance, while different from Regard et al (1991) who showed a significant decline of short term memory performance at altitude, are not surprising given the simple nature of these tasks and the fact that altitude effects can vary with the tasks administered (Banderet & Burse, 1991).

Of the individual sub-components to the multi-task scenario, the addition task produced the most complex results. While the observed improvement at both the sea-level afternoon assessment and the high altitude morning assessments as compared to the sea-level morning assessment could indicate a time of day effect (at sea-level) or improved performance at high altitude, it is more likely that the morning addition performance at sea-level was artificially decreased due to a break in time between the last training period and the morning sea-level assessment (approximately five days). These results emphasize the importance of training days which we used at the beginning of the study period to allow for learning of the task as well as during the moderate altitude staging period to allow participants to return to previous levels of performance (after a five week break).

4.3 Task Practice and Individual Differences

While our results showed that there was variability in task performance during the moderate altitude practice sessions, our training methods were consistent with those of the designer of the SynWin assessment (Elsmore, 1994). In fact, our multiple sea-level and moderate altitude practice sessions far exceeded the practice time utilized by several researchers (Terry, 2002; Cosenzo, 2007; Kearney, 2007; Mastin et al., 2005).

It is likely that some of the variability noted was due to individual differences. Our observation of participants during test sessions showed that some individuals were highly motivated to increase their task performance, whereas others were content to complete the task. Individual differences in task performance and susceptibility to altitude effects have been pointed out by several authors (e.g., Banderet & Shukitt-Hale, 2002;

Leach & Almond, 1999; Kida & Imai, 1993). In fact, Kida and Imai (1993) identified nearly 32% of their participant sample as non-responsive to the debilitating effects of altitude. Further analyses of these data and other cognitive performance data should evaluate the effect of individual differences.

Nonetheless, our data show that a decline in multi-task performance when exposed to high altitude prior to acclimatization as compared to sea-level, is not repeated at high altitude after an intervening stay at moderate altitude. Furthermore, data from that moderate altitude time period was not different from either sea-level or high altitude performance, indicating a stable level of performance that could reflect a positive effect of staging. Additional data collected in this study supports the notion that staging at moderate altitude facilitates acclimatization.

Previously there has been little information regarding whether staging would be effective in improving physical and cognitive performance at higher elevations. These results suggest that the six-day staging period was a successful intervention to increase acclimatization and reduce the negative impact of high altitude on cognitive performance.

CONCLUSIONS

Stationing Warfighters at a moderate elevation *prior to* rapid ascent to a higher altitude has been known to reduce the incidence of AMS and thus has been a recommended military acclimatization strategy. While it may not always be feasible to utilize a staging strategy within military operations, these results suggest that one essential component of Warfighter cognitive performance: multi-task ability involving several domains of cognitive function would be improved by utilizing an acclimatization strategy before ascent to high altitude.

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DISCLAIMERS

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