Acute Effects of Battlefield-Like Stress on Cognitive and Endocrine Function of Officers from an Elite Army Unit

Dr. Harris R. Lieberman, Ms. Christina M. Caruso,
Mr. Philip J. Niro and COL Gaston P. Bathalon
United States Army Research Institute of Environmental Medicine
Military Nutrition Division
42 Kansas St.
Natick, MA 01760-5007
USA

harris.lieberman@na.amedd.us.army.mil; christina.caruso@na.amedd.army.mil;
philip.niro@na.amedd.army.mil; gaston.bathalon@na.amedd.army.mil

ABSTRACT

Military training prepares leaders for the stress of combat. However, there have been few studies of the response of well-trained officers to brief, but intense, operational stress. Recently, during a continuous 53-hour military field exercise designed to produce severe stress in participating officers, we examined changes in various behavioral and physiological parameters. Participants were Captains in the U.S. Army Rangers with an average of 9 years of military service. They were exposed to multiple stressors, including minimal preparation time for the exercise, rapid airborne deployment to an unexpected location, high heat and humidity and unanticipated opposing forces (OPFOR) activity. They received minimal rations, were continuously engaged in physical activity and their performance was being evaluated by command authorities. Under these circumstances, their physical status deteriorated, as indicated by a 5% ($p < .001$) weight loss, consisting primarily of water. Their psychological status, assessed with computer-based cognitive tasks, was severely degraded. Vigilance, reaction time, learning, memory and logical reasoning were impaired ($p < .001$). Self-reported mood-states such as, confusion ($p <.001$), fatigue ($p < .001$), and anger ($p = .009$) increased dramatically. The performance decrements observed were greater than those observed in individuals with a blood alcohol level of 0.1 %, legally drunk in many localities, or suffering from clinical hypoglycemia. In spite of such severe physical and cognitive deterioration, cortisol levels of the volunteers indicated they were experiencing minimal stress. The lack of a classic stress response under such severe conditions indicates that extensive prior training, the selection process and perhaps other factors protected these elite officers from the adverse physiological effects of acute stress.

1.0 INTRODUCTION

Combat is one of the most intense and stressful environments to which humans are exposed. Combat veterans and military historians have written extensively about the unique aspects of this experience, and these observations and their analyses are a rich source of information about the response of humans to severe stress. Although, objective assessment of human behavior in this environment is not generally possible, studies of warfighters engaged in exercises designed to simulate combat can occasionally be conducted [1,2,3,4]. Stressful, realistic training is recognized as a key element of psychological preparation for military operations.

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A key function of such training is to prepare warfighters for the stress of combat. The importance of such training is supported by the history of warfare which demonstrates that performance of well-trained units invariably exceeds that of inadequately prepared opponents. We have had several opportunities to conduct studies during realistic combat training with volunteers from various military units [3,4,5]. In one of these studies, the participants were well-trained officers from an elite infantry unit, the U.S. Army Ranger Regiment [4].

The officers were participants in a continuous 53-hour field training exercise, designed to produce severe, operationally relevant stress. We examined changes in a variety of behavioral and physiological functions before, during and immediately following the exercise. All officers were Captains with an average of 9 years of military experience. They were exposed to a realistic combination of stressors including minimal preparation time prior to the exercise, rapid airborne deployment to an unexpected location, unanticipated opposing forces (OPFOR) activity, and other simulated operational scenarios. In addition, the exercise was conducted in a hot, humid environment, the Rangers received minimal rations, were almost continuously engaged in physical activity and their performance was being evaluated by command authorities. The objective of the study was to quantify the extent of cognitive decrements associated with a multistressor operational environment and concurrently assess various physiological markers, including hormonal factors associated with stress.

2.0 METHODS AND MATERIALS

2.1 Subjects

Thirty-one male volunteers, all Captains in the U.S. Army, participated in this study. The mean (± SEM) age of the volunteers was 31.6 ± 0.4 yrs; their height and weight were 178.5 ± 1.4 cm and 81.5 ± 1.3 kg, respectively. They had served, on average, 9.2 ± 0.5 yrs on active duty. The study was approved by the U.S. Army Research Institute of Environmental Medicine Human Use Research Committee and the U.S. Army Office of the Surgeon General's Human Subjects Research Review Board. All volunteers gave written informed consent prior to participation. Commanding officers were not present when consent was obtained.

2.2 Procedures

This research study was part of a U.S. Army field exercise conducted for training purposes by an elite, light infantry unit, the 75th Ranger Regiment. It consisted of three phases: an in-garrison preparation phase (pre-field); a field exercise; and a concluding garrison phase (post-field). The volunteers' cognitive performance, mood and body composition were assessed once during each phase. The first test session was conducted in a classroom-like setting at 1800 h on Day 1 at the start of the pre-field phase. The unit deployed to the field at 0100 h on Day 3 and was tested on Day 4 at 1200 h in a tent. The final testing session was conducted at 0500 on Day 5 upon return to garrison (post-field phase), but before volunteers could sleep, eat, or rehydrate. Saliva cortisol levels were assessed three times a day during all phases of the study. During the exercise, maximum ambient temperature was 31^{o} C with daily lows reaching 19^{o} C. Average morning humidity was 86%, and average afternoon humidity was 56%.

Throughout the exercise, soldiers engaged in continuous activities including, a parachute drop, travel in small boats, sustained off-road hiking with heavy load carriage and exercises designed to simulate combat, including exposure to simulated explosions and gunfire. Water was available ad libitum. Food intake was minimal, consisting, for the entire duration of the field exercise, of a single standard field ration which provided 5.23 mJ (1250 Kcal) of energy.

2.3 Cognitive and Mood Assessment

We used a battery of tests that provide information on selected cognitive parameters of military relevance. The tests assessed basic functions like reaction time and vigilance, and more complex cognitive functions, such as attention, pattern recognition, memory and reasoning. They are sensitive to various stressors [3,6,7] and were previously employed in military field studies [3]. The cognitive tasks were administered on IBM-compatible laptop computers. Volunteers practiced all tests prior to the pre-field test session.

2.3.1 Four-Choice Visual Reaction Time (RT) Test

This test assesses ability to respond rapidly and accurately to simple visual stimuli. Volunteers were presented with a series of visual stimuli at one of four different spatial locations on the computer screen [8]. They indicated the correct spatial location of each stimulus by pressing one of four adjacent keys on the keyboard. Parameters recorded included correct and incorrect responses, RT, premature errors (responding before presentation of the stimulus), and time-out errors (response latency greater than one second). The test took about five minutes to complete.

2.3.2 Scanning Visual Vigilance Test

This test assesses vigilance, the ability to sustain attention during relatively boring, continuous tasks that generate minimal cognitive load [9,10]. The volunteer continuously scans the computer screen to detect the occurrence of an infrequent, difficult to detect stimulus that appears at random intervals and locations on the screen for two seconds. On average, a stimulus was presented once per minute. Upon detection of the stimulus, the volunteer pressed the keyboard space bar as rapidly as possible. The computer recorded whether a stimulus was detected and time required for detection. Responses made before or after stimulus occurrence were false alarms. Each test session lasted 20 minutes.

2.3.3 Matching-to-Sample Test

This test assessed short-term spatial memory (working memory) and pattern recognition [3,11]. The volunteer began by pressing the arrow key when the word "READY" appeared on the computer, after which an 8 x 8 matrix of a red and green checkerboard pattern was presented. The matrix appeared for 6 seconds, was removed and was followed by a variable delay interval. Then, two matrices were presented: the original matrix and a matrix with the color of two squares reversed. The volunteer attempted to select the matrix that matched the original sample. The task consisted of 20 trials. A response (left or right arrow key) was necessary within 15 seconds or a time-out error was recorded. Correct responses were recorded, as was RT.

2.3.4 Repeated Acquisition Test

This test assessed motor learning, attention and short-term memory [3,12]. Volunteers learned a sequence of 12 keystrokes using the four arrow keys of the computers. The outline of a rectangle was presented on the screen at the beginning of a trial. Each correct response filled in a portion (1/12th) of the rectangle from left to right with a solid yellow block. Each incorrect response blanked the screen for 0.05 seconds. The volunteer learned the correct sequence by trial and error. When a sequence was correctly completed, the rectangle became full, the screen blanked, and another empty rectangle reappeared for the next trial. A session ended when the volunteer completed 15 correct sequences (15 trials). Incorrect responses and time-to-complete each trial were recorded. Ten minutes were required to complete this task.

2.3.5 Grammatical Reasoning

This test was adapted from the Baddeley Grammatical Reasoning Test and assessed language-based logical reasoning [13]. During each trial, a logical statement, such as "A is preceded by B," was followed by the letters AB or BA. The volunteer decided whether or not each statement correctly described the order of the two letters. The "T" key on the keyboard was pressed for correct (true) responses, and the "F" key was pressed for incorrect (false) responses. The subjects had 20 seconds to press a key or a score of no response was recorded. A session lasted for 32 trials and took five minutes to complete.

2.3.6 Profile of Mood States Questionnaire

The POMS is a widely used, standardized, computer or paper-and-pencil administered inventory of mood states [14]. Volunteers rated a series of 65 mood-related adjectives on a five-point scale, in response to the question, "How are you feeling right now?" The individual adjectives factor into six mood sub-scales: tension, depression, anger, vigor, fatigue, and confusion.

2.4 Activity and Sleep Assessment

Actigraphs, model BMA-32 (Precision Control Devices, Ft. Walton Beach, FL), were used to assess patterns of rest and activity (including work-rest cycle), total physical activity, and estimated duration and fragmentation of sleep. These devices are worn on the wrist of the non-preferred hand and are 4 cm in length, 3.1 cm in width, 1 cm high and weigh 57 grams. Total activity counts per day were derived and a validated algorithm determined whether the subject was awake or asleep for each minute [15].

2.5 Body Composition and Hydration Status

Volunteers were weighed on a calibrated electronic battery-powered scale accurate to 0.1 kg (Seca, Birmingham, U.K.). Estimates of hydration status were based on bioelectric impedance spectroscopy (BIS) (Xitron 4000B, Xitron Technologies, San Diego, CA) measurements taken at the pre- and post-field tests and dual energy X-ray absorptiometry (DEXA) (LUNAR Model DPX-L, LUNAR Corporation, Madison, WI).

2.6 Saliva Cortisol

Saliva (5 ml) was collected in salivette tubes (Sarstedt; Newton, NC) on three occasions per day: early morning (approximately 0600 h); midday (1200 h), and late evening (1800 h). Morning (0600 h) samples on Day 3 could not be collected as the volunteers were engaged in training activities that could not be interrupted. Cortisol was determined using standard R.I.A. procedures.

2.7 Statistical Analyses

The cognitive, mood, body composition and hydration data were grouped by session and repeated-measure analyses of variance (ANOVA) conducted. A two-tailed, 0.05 level of probability was used to determine statistical difference. Only post-hoc differences identified using least significant difference (LSD) multiple comparison tests are reported here. The complete results of this study can be found in [4]. Activity and sleep were compared across a baseline period of pre-field activity in garrison versus the field operation using paired-sample t-tests.

3.0 RESULTS

3.1 Cognitive and Mood Test Battery

3.1.1 Four-Choice Reaction Time

Post-hoc tests demonstrated that RT increased 19.5% from pre- to post-field testing ($p<0.001$) (Figure 1). Incorrect responses increased 97.6% from prior to field exercise to during field exercises ($p = 0.01$), and 218.4% from prior to post-exercise ($p < 0.001$). Time-out errors increased in the field ($p < 0.05$) (150%) and post-field ($p < 0.01$) (164%) compared to pre-exercise testing.

3.1.2 Visual Vigilance

When the pre-field test session was compared on post-hoc testing to the field test session and post-field session, correct responses decreased 23% and 24%, respectively ($p < 0.001$), RT increased 22% during both sessions and false alarms increased 363% and 163%, respectively ($p < 0.05$) (Figure 1).

3.1.3 Matching-to-Sample

Post-hoc tests demonstrated correct responses decreased during the field exercise 11% ($p < 0.01$) and post-field exercise 31% ($p < 0.001$) compared to pre-field testing (Figure 1). Reaction time increased from pre-field to the field 26% ($p < 0.001$) and post-field sessions 26% ($p < 0.05$). Time-out errors increased from pre-field testing to field testing by 700% ($p < 0.05$) and post-field testing by 2300% ($p < 0.01$).

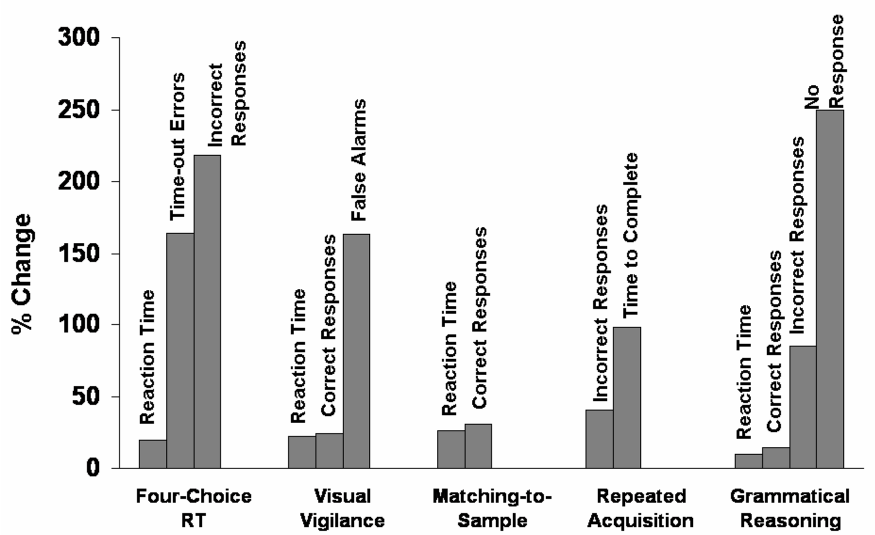

Figure 1: Percent degradation of selected dependent measures from the five cognitive tests administered: Four-Choice Reaction Time, Visual Vigilance, Matching-to-Sample, Repeated Acquisition and Grammatical Reasoning. The percent change is based on comparisons of the post-field test session to pre-field (baseline) test session.

3.1.4 Repeated Acquisition

Time-to-complete increased from pre-field exercise to field training 24% ($p < 0.01$) and between pre-field exercise and post-field assessment 40% ($p < 0.001$) (Figure 1). The number of incorrect responses increased from pre-field to field training and post-field assessment 30% and 98%, respectively ($p < 0.01$).

3.1.5 Grammatical Reasoning

Correct responses decreased across testing periods [pre-field vs. in-field, 6.5% ($p < 0.05$); pre-field vs. post-field, 14.5% ($p < 0.001$)] (Figure 1). Incorrect responses increased 85% ($p < 0.001$) with post-hoc differences detected from pre-field to post-field exercises ($p < 0.001$). Response time was not impaired.

3.1.6 Profile of Mood States

An increase in tension 54%, depression 168%, and confusion 251%, and a decrease in vigor 75% occurred when pre-field scores were compared to post-field results (Figure 2). Fatigue ($p < 0.001$) increased 465% over the course of the study as did anger 86% ($p = 0.009$). All post-hoc comparisons were significant.

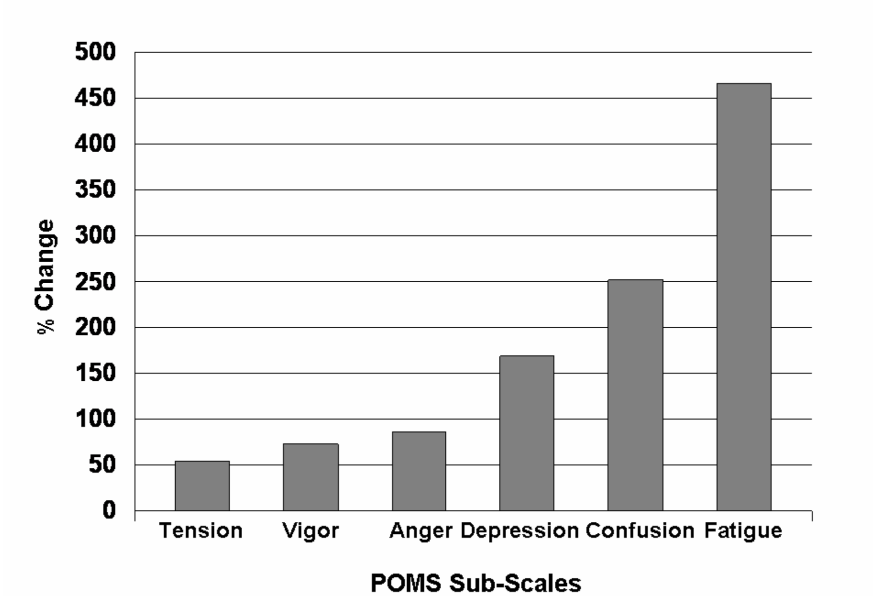

Figure 2: Percent degradation of the six POMS sub-scales, Tension, Vigor, Anger, Depression, Confusion and Fatigue, from the pre-field (baseline) POMS scores to post-field scores.

3.2 Sleep Assessment

During the 27 h prior to the field exercise, subjects slept a total of 5.3 ± 0.2 h (range 2.3-7.5) (Figure 3). This sleep was obtained as a single sleep event (the night of Day 2). During the 53 h subjects were in the field, they slept only 3.0 ± 0.3 h. The mean number of sleep intervals during the field exercise was 14.4 ± 1.0.

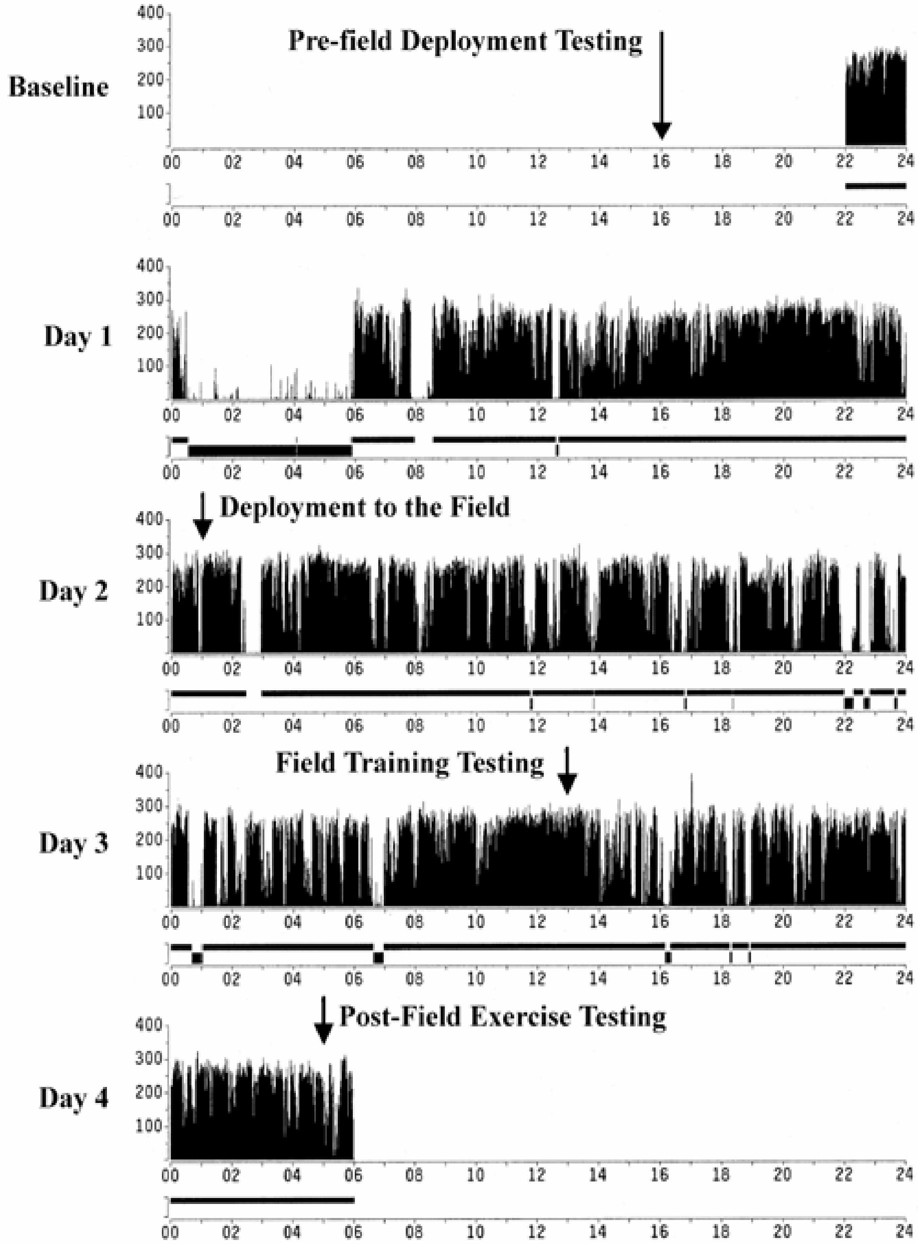

Figure 3: Representative activity monitor (actigraph) data from one Ranger officer continuously collected over the 73 h of the study (including the 53 h of the exercise) [4]. The vertical height of each line plotted on the x-axis represents the number of movements detected in one minute of time. The arrows indicate testing and deployment times. Each day of the study is plotted as a 24-h. period starting at 0000 h. Below the primary x-axis of each day's plot is a second axis which displays estimated sleep versus waking time [15]. The thicker, lower bar on the second axis indicates that the subject is sleeping (upper bar = awake; lower bar = sleep).

3.3 Body Composition and Hydration Status

Body weight assessed by scale declined from 81.5 ± 1.3 kg pre-field to 78.8 ± 1.3 kg on Day 4, and then fell further, to 77.4 ± 1.2 kg at the post-field phase, a 5.0% decline ($p < 0.001$ on ANOVA). Estimated total body water, as assessed by BIS, declined from 47.3 ± 0.8 liters pre-field to 44.2 ± 0.8 liters at the post-field phase, a 6.3% decline ($p < 0.001$). Since substantial measurement error can occur when this technique is used, especially in dehydrated humans, DEXA measurements on randomly selected volunteers were used to verify the BIS results. Measurements of body composition with the DEXA technique are accurate despite variations in the water content of tissue [16]. Dehydration estimated from the DEXA data, when weight loss was partitioned using a three compartment model, was identical to the results from BIS. Mean total water weight loss was 3.1 kg or 3.1 liters with each technique.

3.4 Saliva Cortisol

Mean salivary cortisol varied over time ($p < 0.001$). Post-hoc testing was limited to comparisons of samples collected at the same time of day and pre-field versus post-field samples. During the exercise, cortisol levels were lower in the morning and higher in the evening compared to pre-field measurements taken the same time of day. Typically, morning cortisol levels are higher than evening levels. This disrupted pattern of release is indicative of circadian desynchronization of the officers as a result of the continuous nature of the exercise.

4.0 DISCUSSION

The officers participating in this exercise were exposed to a variety of stressors intended to simulate combat-like conditions. These included: almost total sleep deprivation; continuous activity in a hot, humid environment; substantial dehydration; minimal food intake; and a variety of mentally and physically challenging activities designed to create unexpected and difficult situations. The effectiveness of this combat simulation was verified by a variety of techniques. Extensive loss of weight (5%) occurred in a brief period of time as documented using highly accurate scales and confirmed using DEXA technology. The lack of both sleep and any substantial rest periods during the 53 h of the field exercise was documented using wrist-worn actigraphs which have been validated previously using polysomnography [17]. Extensive decrements in cognitive performance were observed using standardized computer based tests of both simple and complex militarily relevant behaviors. On one simple task of decision making, Four Choice Visual RT, mean degradation in cognitive performance of the Rangers at the end of the exercise was greater than the that of individuals who are legally drunk or clinically hypoglycemic (Figure 4) [4].

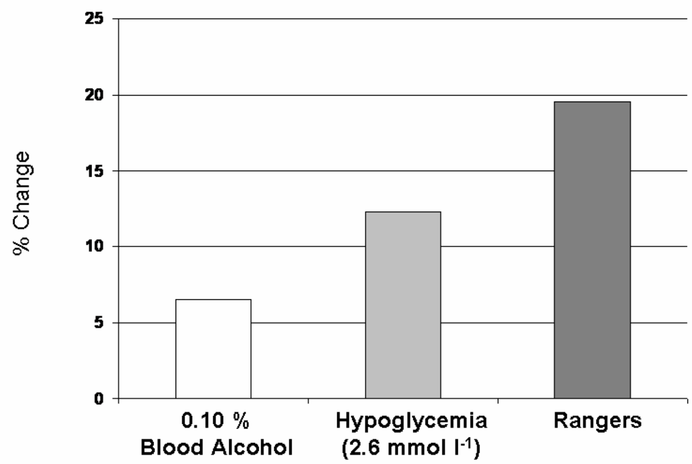

Figure 4: Percent increase in Four Choice Reaction time (RT) latency resulting from alcohol intoxication (blood alcohol = 0.10%) [18] and clinical hypoglycemia (blood glucose of 2.6 mmol l^{-1}) [19] compared to the increase in the same parameter during this study [4].

The standardized self-report mood questionnaire, the POMS, that was administered indicated that self-perceived cognitive status on certain sub-scales had reached a level comparable to that of individuals suffering from diseases such as narcolepsy (fatigue sub-scale), sleep apnea (fatigue sub-scale), depression (fatigue sub-scale), Parkinson's Disease (vigor sub-scale) and Chronic Fatigue Syndrome (fatigue sub-scale) (Figure 5) [20,21,22].

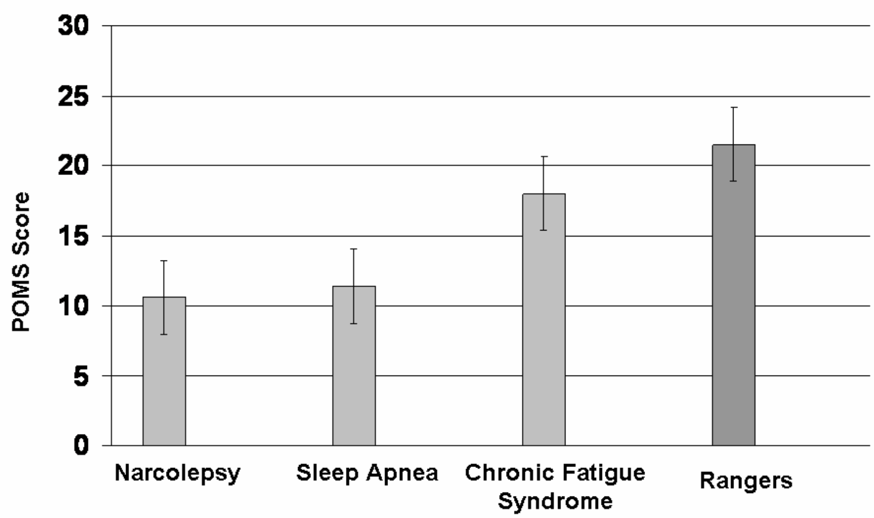

Figure 5: Self-reported POMS Fatigue scores of patients diagnosed with narcolepsy [20], sleep apnea [20] and Chronic Fatigue Syndrome [21] compared to the post-field POMS Fatigue scores of the Rangers in this study.

Although, by any objective standard, the Ranger officers were severely compromised behaviorally and physiologically, they showed little evidence of a classic stress response, which would be indicated by elevated cortisol release. Cortisol levels are widely used to assess the impact of psychological and physical stress on humans and are the most widely accepted marker of hypothalamus-pituitary-adrenal axis (HPA) activation [23,24,25]. Cortisol levels during the field exercise were in the range expected for non-stressed, military volunteers with demographic characteristics similar to our sample (Figure 6) [25]. During intense military field studies conducted with younger, less well-trained volunteers (cadets in a military academy ranging in age from 22-26 yrs), cortisol levels 2 to 3 times above baseline have been observed [26]. In military personnel severely stressed by exposure to a simulated prisoner of war scenario during Survive, Evade, Resist, Escape (SERE) training, cortisol is elevated 5 times above baseline values [25]. When normal volunteers are given exogenous corticosteroids, and in patients with elevated cortisol due to Cushing's syndrome, cognitive performance is substantially disrupted [27,28].

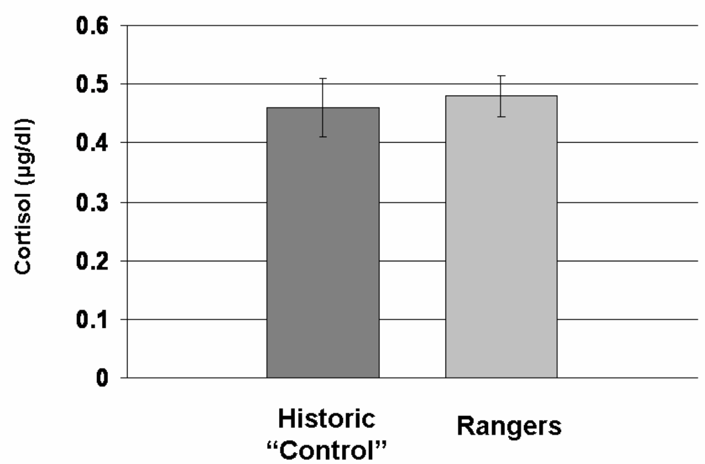

Figure 6: Mean (± SEM) morning and afternoon post-field cortisol levels of the Rangers on Day 4 (PM) and Day 5 (AM) compared with mean morning and afternoon cortisol levels of a group of demographically similar, non-stressed military volunteers [25].

The lack of a substantial endocrine response by the Rangers to the severe stressors they experienced may be an important, objective marker of their resilience. Although, based on the objective behavioural and body composition measures employed, the Rangers were severely impacted by the exercise, they continued to perform their assigned duties, and were cooperative participants in the various voluntary research procedures of this study. It is likely the extensive prior training and experience of the officers protected them from intense HPA activation that would be expected given the severe stressors experienced during the exercise. Although the rationale for such realistic training and the importance of operational experience is not expressed in physiological terms, it appears to have a biological basis. It has been found that HPA activation during exposure to an extremely stressful military environment, survival school, varies depending on prior training. Soldiers from elite units, with substantial prior military experience, exhibit less HPA activation and perform their assigned duties better than age-matched controls with less training [29]. A similar phenomenon has been identified in the civilian literature and termed "stress hardiness" or "toughening" [30]. Of course, the selection process, whereby individuals who maybe inherently "stress-resistant" are chosen and self-select for assignment to elite military units, may explain, in part, these differences.

5.0 CONCLUSION

This study suggests that intense, rigorous and frequent training and operational experience protects warfighters from at least some of the adverse physiological effects of acute stress. The long term consequence of such preparation on the mental health of service members remains to be determined. Of course, it is also possible that highly stressful training, if improperly conducted, could have unintended adverse consequences.

6.0 DISCLAIMER

The views, opinions, and/or findings in this report are those of the authors and should not be construed as an official Department of Defense or Army position, policy, or decision, unless so designated by other official documentation. Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations. Human subjects participated in these studies after giving their free and informed voluntary consent. The investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46.

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