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**EFFECTS OF LEVEL OF DIETARY
SALT RESTRICTION AND MARCHING IN A SIMULATED
DESERT ENVIRONMENT ON RIFLE MARKSMANSHIP**

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**



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**UNITED STATES ARMY
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EFFECTS OF LEVEL OF DIETARY SALT RESTRICTION AND MARCHING IN A
SIMULATED DESERT ENVIRONMENT ON RIFLE MARKSMANSHIP

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CONTENTS

	<u>Page</u>
Contents	iii
List of Figures and Tables	iv
Acknowledgements	v
Executive Summary	1
Introduction	3
Methods	4
Participants	4
Procedures	5
Statistical Analyses	7
Results	8
Repeated Exercise and Heat: Effects on Marksmanship	8
NaCl Level in the Diet: Effects on Marksmanship	8
Physiological Predictors of Marksmanship	10
Discussion	12
Conclusions	14
References	16
Appendix	19
Distribution List	21

LIST OF FIGURES AND TABLES

	<u>Page</u>
Figure 1. Percent of targets hit after an 8-hour heat exposure (walk-rest scenario) in a simulated desert environment.	9
Table 1. Effects of dietary NaCl on rifle marksmanship ($\bar{X} \pm S.D.$) over six days of testing.	10
Table 2. Mean ($\pm S.D.$) values of selected physiological variables compared by level of NaCl in the diet.	11
Table 3. Summary of regression analysis for the 8 g NaCl diet including equation and significance level of contributing variables.	12
Figure A-1. Effects of intermittent exercise in a simulated desert environment on rifle marksmanship.	20

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EXECUTIVE SUMMARY

Rifle marksmanship using the Weaponeer was assessed after walking (1.56 m/sec, 5% grade, 30 min/hr, 8 hr/day, 10 d) in the heat (41°C, 20%RH). Participants (17 male soldiers) consumed a diet containing 4 g or 8 g NaCl per 24 hours throughout testing. The influences of repetitive heat-exercise exposures, NaCl level in the diet, and physiological responses to heat stress upon rifle shooting were examined. Marksmanship measures included hitting a pop-up target at simulated distances of 100 m and 250 m, and shooting at a stationary zeroing target at a 25-m simulated distance. Participants fired 32 shots at the pop-up targets and nine shots at the zeroing target. Marksmanship testing was done every other day for 10 days after completing eight hours of exercise in the heat.

A significant drop in the percentage of 250-m pop-up targets hit occurred only after the first day of heat exposure ($p < 0.05$). No differences occurred for the 100-m pop-up target, or the various 25-m stationary target measures. Plasma volume loss was significantly correlated ($R = 0.64$, $p < 0.01$) with distance from the centroid of mass (DCM) for the group consuming the 8 g NaCl diet.

The findings indicated that: 1) initial heat/exercise exposure elicited a decrement in shooting accuracy (250 m) 2) an insignificant but consistent trend favored the 8 g NaCl diet with respect to shooting performance, and 3) plasma volume losses were correlated with DCM for the 8 g NaCl dietary group.

INTRODUCTION

The effects of work in a hot-dry environment on rifle shooting accuracy is of extreme importance, especially to troops stationed in desert areas of the world such as Southwest Asia. Previous research has revealed rifle shooting accuracy is poorer during and after heat exposure [13,21,22]. Possible causes cited include reduced muscular control [13] dehydration from excessive sweat loss, and inadequate fluid consumption [22]. Decrements in shooting accuracy after exposure to ambient heat (greater than 32.2°C) have been demonstrated both under laboratory conditions and in the field. For example, in a field study conducted in a desert environment, a slow 1.18 m/sec march in the heat (29.4°C, 40% RH) resulted in a reduction in shooting accuracy that was attributed to an increased heart rate due to increased body heat storage [21].

Similarly, intense aerobic exercise has also been shown to have a negative impact on rifle shooting performance [8,16,18,19,20]. Elevated heart rate and numerous body tremors due to exercise-induced fatigue [16,19], and body sway [18] have been offered as possible explanations for the disruptions in shooting accuracy.

While the daily salt (NaCl) requirements of many tropical inhabitants are low and range from 2 to 8 g [6], various consequences of low NaCl intake in the heat have been observed. Some individuals who have low levels of NaCl may be at increased risk of heat injury or illness [1,12]. Studies using heat-exercise acclimation suggest that diets providing between 4 g and 8 g of NaCl per day are sufficient to maintain health and performance of a soldier working in a tropical or desert environment [2,6], since heat acclimation reduces the amount of NaCl lost in the sweat and urine [10].

No effects have been reported for a combination of work in a desert environment while consuming low levels of NaCl for individuals who normally consume 8 to 15 g of NaCl per day. However, dietary restriction of NaCl may affect various psychomotor tasks due to large NaCl losses that occur through sweat, when NaCl levels are not being replaced. These losses will occur at least initially, and possibly over continuous days of exercise in the heat because of lack of acclimation. Armstrong et al. [1] reported that during acclimation to the heat, individuals who consumed 23 g of NaCl had lower heart rates

than those consuming 5.7 g of NaCl. Previous research has documented that higher heart rates are detrimental to shooting accuracy [21]. Low dietary levels of NaCl may compromise a variety of biological functions including nerve conduction, brain function, muscle contraction, blood pressure maintenance and electrolyte balance [11], all important to military tasks such as rifle marksmanship. An investigation of a low salt diet is particularly important because the NaCl consumption usually drops during field operations from the amount normally consumed in garrison dining halls. Understanding this NaCl-heat/exercise-performance interaction is extremely important to tactical military operations. Rapid deployment to a desert environment is not uncommon as evidenced by Operation Desert Shield/Desert Storm.

The purpose of this study was to assess the combined effect of dietary NaCl intake and aerobic marching over ten days in a simulated desert environment on rifle marksmanship performance. This investigation sought to answer the following three questions. Does a low NaCl (4 g) diet negatively impact shooting accuracy because of the physiological stress associated with NaCl and sweat loss during exercise in the heat? Does acclimation to exercise in the heat attenuate potential decrements associated with acute heat and exercise exposure? How do the various physiological changes associated with exercising in the heat affect rifle marksmanship?

METHODS

Participants

Participants were 17 male soldiers who were not acclimated to the heat. All were medically evaluated and participated in this study after giving their free and informed voluntary consent. Participants were randomly assigned to a daily regimen of either a low NaCl (4 g) or moderate NaCl (8 g) diet. Dietary assignment was done in a double-blind manner. Examination of anthropometric characteristics (age, height, weight, and race) indicated the two groups were similar. The participants assigned to the 4 g or 8 g NaCl diets respectively, averaged 19.8 and 19.9 years of age; were 181.1 and 180.1 cm tall; and weighed 78.9 and 77.0 kg. All participants were Caucasian except for one Hispanic in each group.

Procedures

There were two iterations of this study. Participants were administered an 8 g NaCl equilibration diet for a period of seven days prior to heat exposure and exercise. During both the stabilization period and test period, participants were confined to the experimental test area. Technicians were present at all times to ensure that participants did not leave or consume additional food. Following the stabilization period, participants were placed on either the 4 g or 8 g NaCl diet, and they exercised in an environmental chamber in a hot dry environment (41°C, 20%RH, 1.2 m/sec air speed) for ten consecutive days. Participants were therefore sequestered for a total of 17 days. Exercise consisted of walking on the treadmill intermittently for eight hours. Participants walked at 1.56 m/sec at 5% grade for 30 min each hr. Following each exercise bout, participants rested for 30 min. This alternating work-rest cycle was repeated over the course of eight hours. Participants wore only shorts, socks and running shoes. After each test period, participants stayed in a dormitory room in the same building for the balance of each day at an ambient temperature of 21°C during the night to complete the 24-hr period between the simulated desert marches.

Weights were recorded at the beginning and end of each rest period, and volunteers were encouraged to maintain starting weight by *ad libitum* water consumption during both the exercise and rest periods. Rectal temperature and heart rate (HR) were monitored regularly throughout testing. If a participant's rectal temperature exceeded 39.5°C or rose by greater than 0.6°C during any five-min period, or if HR exceeded 180 beats/min (for a five-min period) the participant was removed to a cool environment for the remainder of that day's testing. He was allowed to return to the heat/exercise scenario the following day after receiving medical clearance. Ratings of perceived exertion (RPE) were obtained near the end of each exercise interval.

The Weaponeer (Spartanics, Ltd., Rolling Meadows; IL) M16A1 rifle marksmanship simulator was used to assess marksmanship performance. The Weaponeer consists of a demilitarized rifle and four scaled targets: a 100-m pop-up human silhouette target, two 250-m pop-up human silhouette targets and a 25-m zeroing target.

The procedure for training (testing procedure is described below) was similar to that described by Johnson, McMenemy, and Dauphinee [14]. Participants fired from a

simulated foxhole position with the rifle supported by sandbags. Each participant first fired a set of nine self-paced shots at a 25-m zeroing target until a tight shot group was recorded (8 of 9 shots falling within a .95 X .95 cm square). The participant then fired at 32 randomly presented pop-up targets at simulated 100-m and 250-m distances. Each 100-m target appeared for three seconds, while each 250-m target appeared for six seconds. The time interval between the disappearance of one target and the presentation of the next was one second. A target would fall when hit, and it would remain standing when not hit; this gave the participant immediate feedback.

All marksmanship training and testing was done in a room adjacent to the heat chamber. Participants received four days of training during dietary stabilization DAYS 1-7, with an average of 100 rounds per day. After the fourth practice day, DAY 7, a baseline marksmanship measure was taken. Ambient temperature in this location was approximately 21°C. Participants were tested on the Weaponeer every other day during the heat acclimation period (DAYS 8-17). Testing (8-10 min duration) included nine shots at the 25-m zeroing target and 32 shots at the randomly appearing 100-m and 250-m pop-up targets. The marksmanship assessment occurred approximately 20 min after the final 30 min exercise bout. A maximum of five participants were tested on any one day.

Graphical representations of the target were obtained from the Weaponeer's paper printout record. The shots on the zeroing 25-m target were digitized using a 30.5 X 30.5-cm digitizing tablet (Jandel Scientific, Corte Madera, CA). The data were converted to actual shot displacement distances and analyzed statistically. The values presented must be multiplied by a factor of 350 to represent actual distances from target center on the standard 49 cm wide rifle-range military human silhouette. The X and Y coordinates for the sets of nine shots obtained from digitizing the paper printouts were entered into a data file and the following marksmanship parameters were calculated [17]:

Distance from centroid of mass (DCM) = distance (mm) from the center of impact of the shot group to the center of the human silhouette target.

Shot group tightness (SGT) = area (mm²) of the shot group; i.e., the maximum horizontal distance (X axis) multiplied by the maximum vertical distance (Y axis) between shots.

Horizontal shot group tightness (HSGT) = distance (mm) from the left-most shot to the right-most shot; i.e., the range along the X axis.

Vertical shot group tightness (VSGT) = distance (mm) from the lowest shot to the highest

shot, i.e., the range along the Y axis.

Horizontal deviation (HDEV) = distance (mm) along the X axis from the center of the shot group to the center of the target. A negative value indicated a shot to the left, and a positive value indicated a shot to the right, of the center of the target.

Vertical deviation (VDEV) = distance (mm) along the Y axis from the center of the shot group to the center of the target. A negative value indicated a shot below, and a positive value indicated a shot above, the center of the target.

On a Cartesian coordinate system, the target center is the origin (0,0), the average shot group location is (HDEV,VDEV) and the DCM is the distance (mm) from (HDEV,VDEV) to the origin.

The actual combination of 100-m and 250-m targets presented on each test occasion varied because of the random generation of target presentation but a total of 32 targets appeared. Therefore, scoring of the pop-up targets was recorded as a percent of targets hit (out of the number of targets presented) for both the 100-m and 250-m targets.

Statistical Analyses

Each marksmanship measure (100 m % hit, 250 m % hit, DCM, SGT, HSGT, VSGT, HDEV, and VDEV) was analyzed via a series of two-way repeated measures analyses of variance (ANOVA) using diet group (4 g/8 g NaCl diet) by day (Baseline: DAY 7, and heat/exercise days: DAYS 8-17). For review, marksmanship training was done on DAYS 1-7. A baseline measure was obtained on DAY 7. Marksmanship testing was done after heat/exercise exposure on DAYS 8-17. Participants were tested every other day because of time constraints. Even numbered participants were tested on even numbered days and odd numbered participants were tested on odd numbered days. Duncan's post-hoc tests were used to determine the location of significant differences obtained via the repeated measures ANOVA. Level of statistical significance for all tests was set at $p \leq 0.05$.

Regression analyses were used to predict DCM, SGT, and percent of targets hit from four potentially important physiological variables affected by exercise in the heat: body weight loss (BWL), HR, percent plasma volume loss (PVL), and RPE. These measures as stated earlier were taken approximately 25 min prior to marksmanship testing.

RESULTS

Repeated Exercise and Heat: Effects on Marksmanship

No significant differences in the zeroing target measurements were observed across test conditions. Means of these various measures for the baseline and over the five heat/exercise exposure marksmanship assessment days may be found in Figure A-1 in the Appendix. These measures combine the 4 and 8 g NaCl groups since no significant differences between groups in the various measures existed.

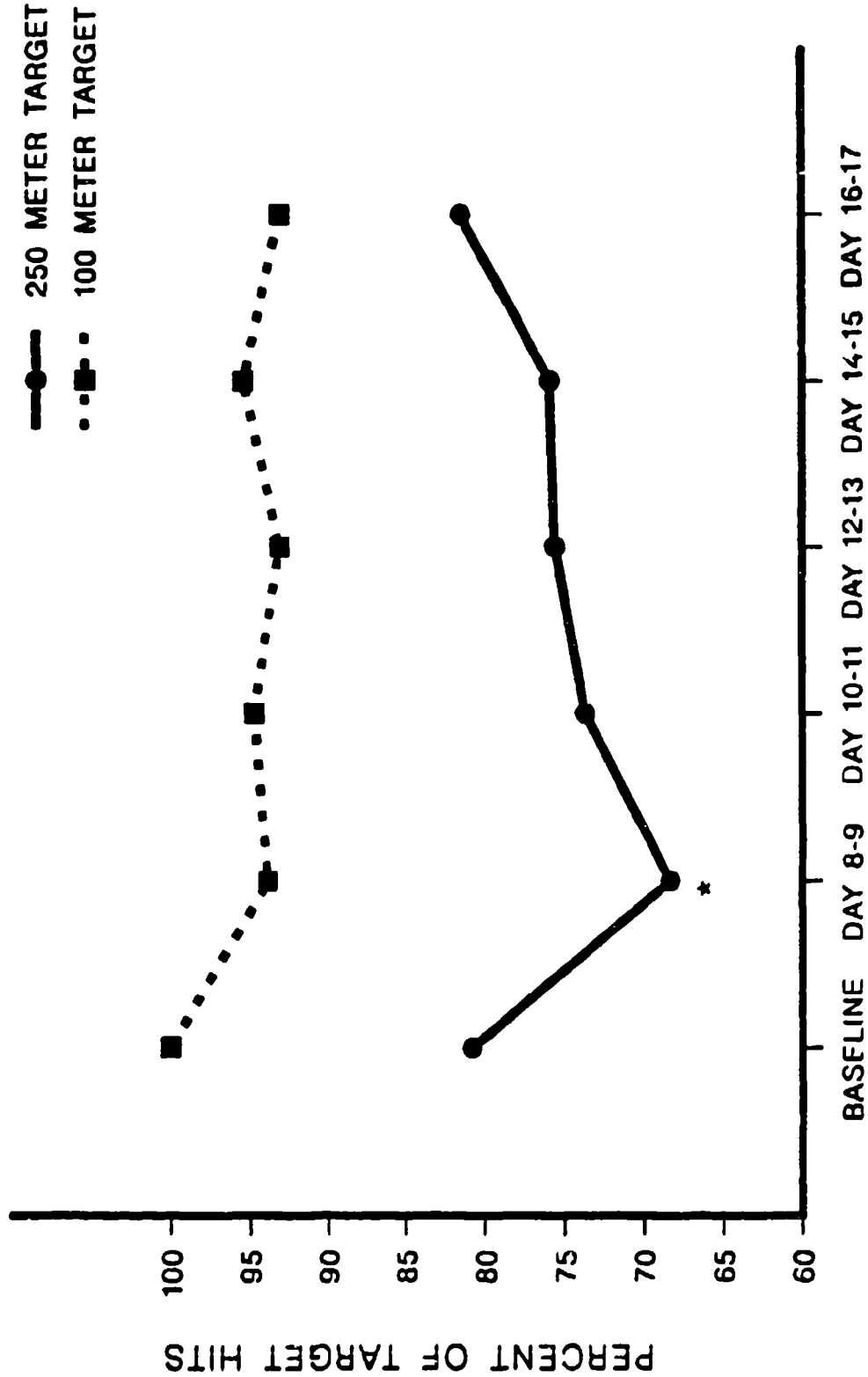
No significant differences were observed for percentage of hits for the 100-m target across the five post heat/exercise marksmanship assessment days compared to baseline (Figure 1). A significant effect ($F=2.28, (5,75), p \leq 0.05$) of exercise in the heat existed, however, for the 250-m targets over the six marksmanship assessment days (baseline and post heat/exercise assessments) as shown in Figure 1. Using Duncan's post-hoc multiple comparison tests, a significant ($p \leq 0.05$) decrease in the percentage of targets hit was observed on the first shooting day in the heat (DAYS 8 and 9) compared to baseline (DAY 7). By the final evaluation day (DAYS 16 and 17) the percent of targets hit did not differ from baseline (DAY 7) and thus had significantly improved from the decrement observed during the first day trial following exercise in the heat (DAYS 8 and 9). Shooting trials which occurred on DAYS 10-15 showed a gradual improvement and were not significantly different from any of the other shooting trials.

Due to foot blisters and thigh chafing there was some variation day-to-day (both within participant and between participants) in the number of walks completed. Using the number of walks as a covariate, however, produced no differences in marksmanship results. Total distance walked for the ten days between the 8 g (185.4 ± 10.1 km) vs 4 g (168.7 ± 18.9 km) NaCl groups was not statistically significant.

NaCl Level In the Diet: Effects on Marksmanship

A significant diet by heat/exercise interaction existed for VSGT ($F=2.57, (5,75), p \leq 0.05$). However, analyzing a change from baseline produced no significant differences either between groups or across days for VSGT. Therefore, the primary difference observed creating the significant interaction was that the two groups started out different. No other

FIGURE 1: PERCENT OF TARGETS HIT AFTER AN 8-HOUR HEAT EXPOSURE (WALK-REST SCENARIO) IN A SIMULATED DESERT ENVIRONMENT



* DAY 8-9 250-m TARGET WAS SIGNIFICANTLY LOWER THAN BASELINE OR DAY 16-17
BASELINE TESTING WAS DONE ON DAY 7 OF THE STUDY

interaction effects existed. Means and standard deviations for the various marksmanship measures by level of NaCl in the diet are shown in Table 1. No significant main effects between the two diet groups were observed for any of the marksmanship measures. However, a consistent trend exists that shows greater accuracy for those consuming the 8 g NaCl diet than those consuming the 4 g NaCl diet.

TABLE 1

Effects of Dietary NaCl on Rifle Marksmanship ($\bar{X} \pm S.D.$) Over Six Days of Testing.

Marksmanship Variable	4 g NaCl Diet Mean \pm S.D.	8 g NaCl Diet Mean \pm S.D.
100 m Target (% hit)	94.03 \pm 6.80	95.00 \pm 9.35
250 m Target (% hit)	69.63 \pm 25.30	75.93 \pm 20.96
DCM (mm)	6.34 \pm 2.28	6.20 \pm 2.38
SGT (mm ²)	117.34 \pm 74.03	98.37 \pm 68.45
HSGT (mm)	9.55 \pm 3.48	9.39 \pm 4.01
VSGT (mm)	12.20 \pm 5.52	9.79 \pm 3.67
HDEV (mm)	3.19 \pm 2.45	2.29 \pm 2.65
VDEV (mm)	0.90 \pm 3.87	-0.47 \pm 4.07

Physiological Predictors of Marksmanship

Table 2 depicts means and standard deviations of the various physiological measures by diet group that were recorded closest to the time of marksmanship assessment; all measures were obtained within one hour prior to the marksmanship testing period.

TABLE 2
Mean (\pm S.D.) Values of Selected Physiological Variables
Compared by Level of NaCl in the Diet

Physiological Variable	4 g NaCl Diet Mean \pm S.D.	8 g NaCl Diet Mean \pm S.D.
Body Weight Loss (%) (BWL)	- 0.40 \pm 0.41	- 0.23 \pm 0.85
Rating of Perceived Exertion (6-20 scale) (RPE)	10.30 \pm 2.71	10.90 \pm 2.42
Plasma Volume Loss (%) (PVL)	7.42 \pm 4.35	6.66 \pm 4.61
Heart Rate (bpm) (HR)	127.20 \pm 16.42	138.00 \pm 19.83

No significant differences between the two diet groups existed for any of the physiological measures cited. The 8 g NaCl diet equation significantly predicted DCM from the physiological variables, while the 4 g NaCl diet equation did not. Initially, all the variables were included in the regression equation. However, calculations indicated that BWL and HR did not contribute significantly and were omitted from the equation (Table 3). DCM and PVL were highly correlated with a correlation coefficient of $R= 0.64$, $p<0.01$. The DCM and RPE correlation was not significant, $R= -0.28$. No other equations significantly predicted any rifle marksmanship measure.

TABLE 3
Summary of Regression Analysis for the 8 g NaCl Diet
Including Equation and Significance Level of Contributing Variables

DCM = .36 PVL - .53 RPE + 9.64

OVERALL EQUATION $F = 11.37 (4,5), p \leq 0.01$
 $R^2 = 0.95$

CONTRIBUTING VARIABLES

PVL	$t = 7.39 (9), p \leq$
RPE	$t = 5.70 (9), p \leq 0.01$

NON-CONTRIBUTING VARIABLES

BWL	$t = .35 (9), NS$
HR	$t = .46 (9), NS$

DCM = Distance from Centroid of Mass
PVL = Plasma Volume Loss
RPE = Ratings of Perceived Exertion
BWL = Body Weight Loss
HR = Heart Rate

DISCUSSION

It is critical to note that marksmanship changes associated with exercise in a desert environment while consuming a low or a moderate NaCl diet comprised only one part of a multidisciplinary study. Details of other sub-studies which address the hormonal, physiological and psychological responses of the participants may be found in Chapters 12-14 of the book: *Nutritional Needs in Hot Environments: Applications for Military*

Personnel in Field Operations [3,9,15].

While rifle marksmanship at 250 m was impaired by exercise in the heat during the very early stages of the heat acclimation interval, the heat-exercise regimen did not significantly affect the various zeroing target measures, or shooting at a 100-m target. Prior research has shown that heat exposure can affect rifle marksmanship accuracy [13,22]; moreover, exposure to various stressors has shown that more complex or difficult tasks are more susceptible to performance breakdowns [4,5,7]. Clearly, hitting a target at 250 m which is visually displayed for only six seconds requires greater shooting precision than shooting at targets 100 m or 25 m away. The complete return to control levels of shooting accuracy while firing at the 250-m target (after nine to ten days of heat exposure) is likely a result of heat acclimation. Cardiovascular adaptations usually take place after the first 2-5 days of moderate exercise in the heat [23].

Dietary NaCl content did not significantly affect marksmanship accuracy. It must be noted though that every measure (see Table 2) indicated a trend towards greater accuracy among the group consuming the 8 g NaCl diet (e.g., more target hits, decreased DCM and SGT). However, in general, the combined effects of diet, exercise, and heat exposure did not elicit decrements in performance commensurate with the apparent level of stress imparted by this combination. In this regard several important points must be considered, for example:

- 1) The level of NaCl in the diet and daily exercise did not affect rifle marksmanship.
- 2) Perhaps most importantly, marksmanship measures were not assessed while still in the simulated desert environment or immediately after the last walk. All but the most complex task were not affected because participants recovered from the heat/exercise stress well enough to fire at the targets successfully.
- 3) The intensity of exercise was at most, moderate.
- 4) Attention to participants' health status took precedence over marksmanship assessment. On the first day of heat exposure two participants were removed before completing the eight hours of exercise in the heat, because of an excessive heart rate and hypotension. Their marksmanship data were not obtained although it is likely that effects of diet and/or exercise in the heat may

have produced significant drops in most accuracy measures.

- 5) A number of no-walk sessions were recorded as a result of leg and foot problems such as blisters and muscle strains. These no-walk sessions of which there was an average of 35% per participant certainly dampened the metabolic stress imposed by exercise in the heat, thus negating potential effects of diet on rifle marksmanship.

Marksmanship was predicted by a few specific physiological indices when consuming the 8 g but not the 4 g NaCl diet. Statistical analysis indicated that plasma volume loss, but not perceived exertion, was significantly correlated with DCM. The regression equation indicated that the majority of the variability in DCM was explained by the percent change in plasma volume ($R=0.64$). The correlation of RPE and DCM was much weaker ($R=-0.28$), and that PVL and RPE are related, $R=0.50$. Previous research has cited heart rate and breathing changes, in response to various stressors, as possible causes in shooting problems [16,18,19,21]. The large plasma volume losses observed in this study which are detrimental to marksmanship accuracy are probably responsible as a result of the associated stress they put on the cardiorespiratory system.

CONCLUSIONS

- 1) Exposure to the combined heat and exercise condition on DAYS 8 and 9 caused soldiers to hit fewer pop-up targets at 250 m; as soldiers became heat acclimated, their accuracy returned to baseline levels. The 250-m pop-up target task was the only task affected by the environmental stress, probably because of the task's difficulty.

- 2) Consumption of a 4 g NaCl diet did not affect rifle marksmanship significantly. Two interpretations are possible. The first is that there are no decremental effects of a 4 g NaCl diet on shooting accuracy after exercising in the simulated desert environment on repetitive days. The second is that the experimental constraints of the study did not allow potential statistical effects to be manifested. Consistent with this possibility is the observation that all eight marksmanship measures were more accurate in the group

consuming the 8 g NaCl diet. A future study examining shooting accuracy in the heat without a recovery period is recommended before the impact on marksmanship of a low NaCl diet and exercise in the heat can be fully determined.

3) Plasma volume losses were correlated with a single measure of marksmanship accuracy (DCM), but only under the 8 g dietary NaCl condition.

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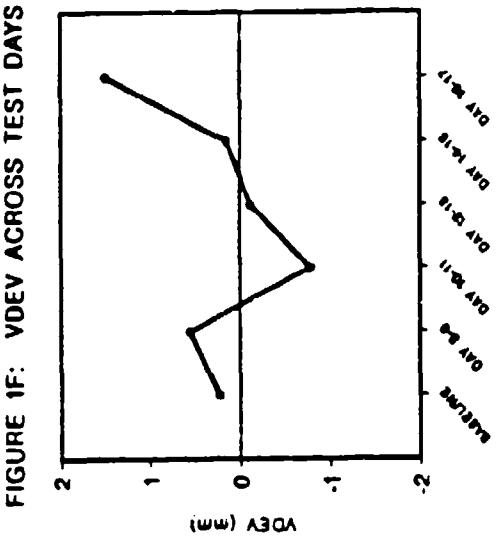
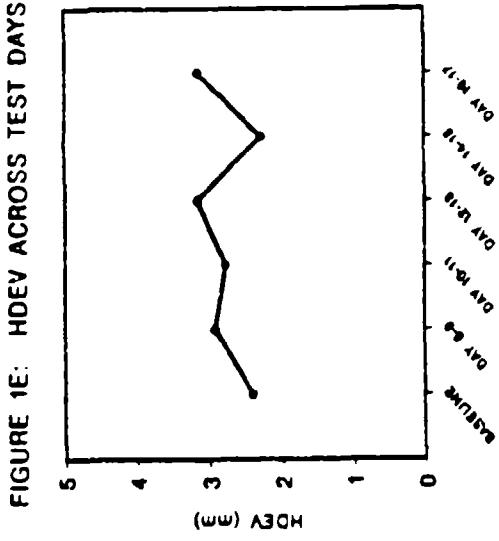
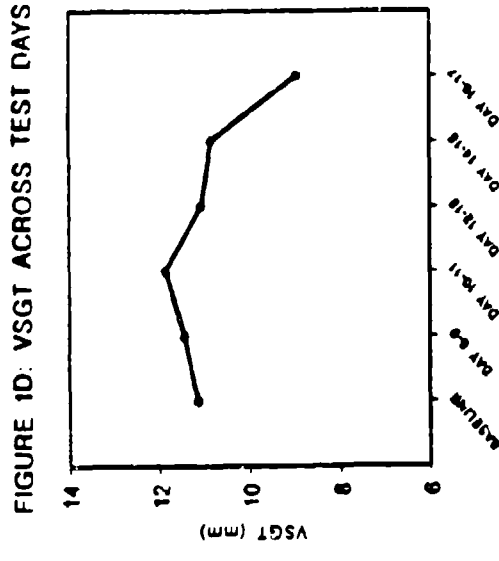
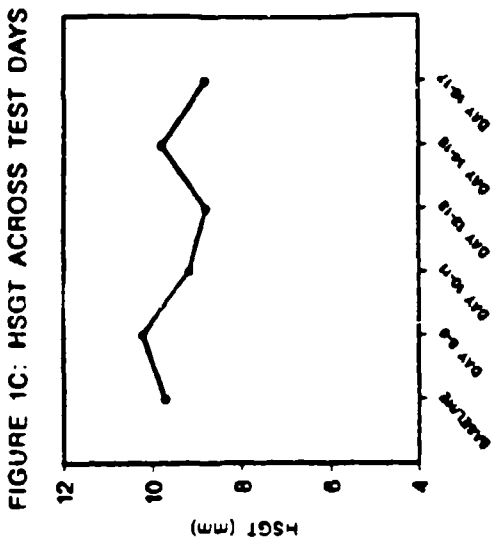
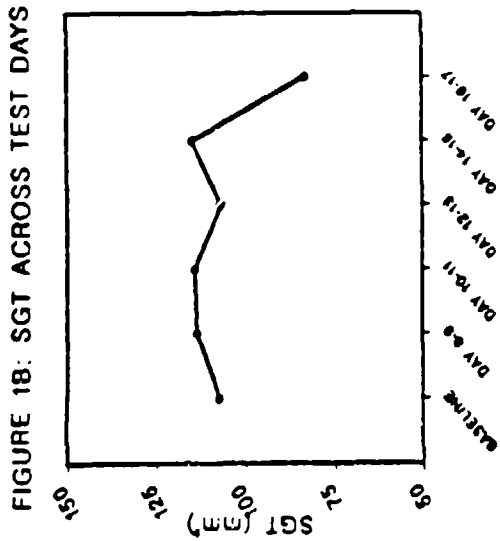
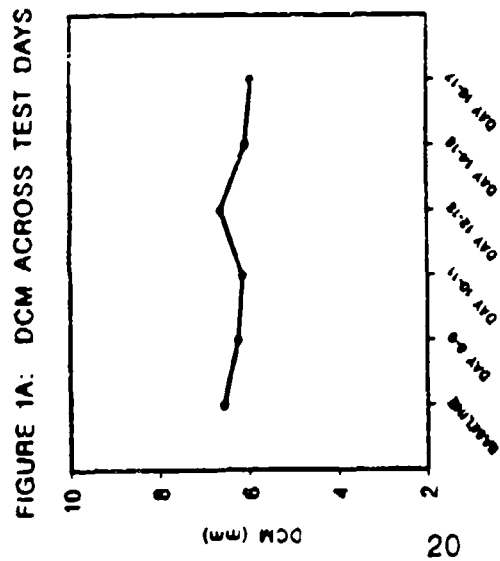
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APPENDIX

FIGURE A-1: EFFECTS OF INTERMITTENT EXERCISE IN A SIMULATED DESERT ENVIRONMENT ON RIFLE MARKSMANSHIP



BASELINE TESTING WAS DONE ON DAY 7 OF THE STUDY

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