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REPORT No. 90-18

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BETHESDA, MARYLAND

MILITARY OPERATIONS IN THE COLD: EFFECTS ON ANAEROBIC-MUSCULAR PERFORMANCE AND SELECT BLOOD INDICES*

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*Report No. 90-18 was supported by the Naval Medical Research and Development Command, Department of the Navy, under Research Work Unit MR04101.07-6004. The views expressed in this article are those of the authors, and do not reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. Approved for public release, distribution unlimited.

SUMMARY

This study examined the effects of military field operations (MFO) under different environmental conditions on anaerobic performance (ANP). U. S. Marines were tested in the field under the following conditions: 1) non-cold environment (NC; n=30, 10 to 32° C), and 2) a cold environment (CO; n=32, -2 to -22°C). Subjects performed 30 sec Wingate tests (WIN), 2 min push-ups, and hand-grip strength pre- and immediately post-MFO to assess ANP. The MFO consisted of ~4.5 days of combat training maneuvers while carrying field equipment (packs and weapon, ~25 kg). WIN measures obtained were absolute and relative mean power (MP), 5 sec peak power (PP), and fatigue index (FI; % decline). Significant main effects ($p<0.01$) were observed for time (pre-post MFO). Reductions occurred in absolute MP (651.8±30.3 to 616.4±28.5 W; X+SE) and PP (897.8±41.6 to 857.0±39.1 W); however, no effect on FI was seen. Significant interaction effects ($p<0.05$) were observed in relative measures. Reductions (pre-post) in MP (NC=8.64±0.16 to 8.37±0.14 W/kg; CO=8.91±0.26 to 8.04±0.15 W/kg) and PP (NC=11.80±0.24 to 11.61±0.33 W/kg; CO=12.23±0.35 to 11.20±0.19 W/kg) were greater under CO than NC conditions. These changes were found despite significant ($p<0.05$), but comparable, pre-post weight reductions in both C and NC conditions. No changes were observed for the push-up or hand-grip tests. Results of blood-urine profiles (pre- to post-MFO) suggested tissue damage and substrate unavailability were contributors to decreases in MP and PP. The data suggest; 1) WIN performance is reduced by participation in MFO, and 2) cold exposure augments these responses when accounting for body weight changes.

INTRODUCTION

Many reports have established the existence of negative physiological and psychological effects developing in humans due to prolonged cold weather exposure (1,9,13,16,22). Dehydration, soft tissue injuries, increased energy expenditure, elevated fatigue, depression, and impaired cognition are a few of the problems associated with exposure to this environment. Furthermore, it is well established that during extended military field maneuvers extreme physical demands are placed on personnel (13,14). The combined effects of an adverse environment and high physical workloads can significantly degrade human performance. This latter issue, decrement of human performance, is a key concern of military biomedical researchers because of the potential impact to the success of military operations (7).

Recent research suggests many physical activities occurring during military field maneuvers place a high dependency upon the anaerobic energy system of the body (2,5,11). Furthermore, research indicates both cold exposure or excessive physical activity can compromise the functioning of the anaerobic energy system (7,9,23,25). The amount of research examining the interactive effects of physical activity and the environment on the anaerobic energy system is sparse (19,26). The intent of this study was to expand this limited knowledge and evaluate anaerobic based performance during military field operations (MFO). This was achieved by examining the effects of cold and non-cold MFOs upon anaerobic power and muscular strength-endurance in U. S. Marines. Additionally, select blood (serum enzymes and lactate) and urine measures (ketones) were evaluated to assess the potential causative factors for any performance changes observed.

METHODS

Subjects: The subjects in this study were 62 male U. S. Marines, aged 18 to 28. Their physical characteristics appear in Table 1. Prior to participating, all subjects were briefed on the nature of the study, and given voluntary written consent to act as human subjects.

TABLE 1. Physical Characteristics of the Subjects (X ± SD)

Condition	Cold (n=32)	Non-cold (n=30)
Age (yr)	21.1±0.4	22.6±0.6
Height (cm)	175.7±0.9	178.6±1.7
Weight (kg)		
Pre-MFO	76.2±2.0	76.3±2.9
Post-MFO	75.1±2.0	74.6±2.7
Body Fat (%)	14.5±0.9	13.1±0.8

Testing Methodology: After subjects reported to the laboratory area, height and body weight were taken (±0.5 cm and ±0.05 kg, respectively). All measures obtained were corrected for any clothing worn by the subject. Neck and abdominal circumferences, and tricep, bicep, subscapular, and supraillium skinfolds were taken to determine percentage of body fat (8,15). Following this, a blood sample was acquired by a venipuncture from a forearm vein. The blood sample was allowed to clot, centrifuged at 2000g x 10 min, and the separated sera was aliquoted and stored at -20° C until later analysis. Serum was

analyzed for lactate, creatine phosphokinase (CPK), lactate dehydrogenase (LDH), and aspirate aminotransferase (AST) levels. A urine specimen was also collected and immediately analyzed for ketone concentration. No active physical testing was performed prior to obtaining any of these measures.

Anaerobic power was assessed by using a modified Wingate cycle ergometer test (4,9). This test consisted of a 3 minute warm-up at ~30 W, followed by maximal pedal revolutions against a relative resistance setting (0.095 x body weight [kg]) for 30 seconds. The test was followed by a 3-4 min cool-down at ~30 W. During the test, pedal revolutions were counted with a micro-switch mounted on the cycle ergometer (Monark #818), and interfaced with a strip chart recorder. Measures obtained from this test were; absolute 30 sec mean power (Watts [W]), relative 30 sec mean power (W/kg bodyweight), absolute 5 sec peak power (W), relative 5 sec peak power (W/kg body weight), and fatigue index (% = last 5 second power output/first 5 second power output x 100) (4). Subjects also performed hand grip and push-up tests to assess muscular strength and endurance. The hand grip test was performed on a military modified (rifle grip) hand grip dynamometer (11). Each subject performed three maximal trials with each hand. Responses were recorded in kilograms. Between each hand grip trial, the subjects were allowed to rest approximately 30 sec. The best effort for each hand was used in the statistical analysis. Typically, a 45-60 minute rest period separated these trials from the Wingate testing session. The push-up test was a two-minute trial in which subjects attempted to perform as many push-ups as possible in correct form (11). The total number of push-ups served as the measure of this test.

Additionally, an exercise lactate response was assessed in each subject during a submaximal cycle ergometer (Monark # 868) test. Subjects were first allowed to rest approximately one hour from previous tests. Each subject then completed a 2 minute warm-up (no resistance), followed by 30 W increases every minute until 240 W was reached. A finger tip blood sample was taken at 210 W (minute 6-7), and analyzed for lactate levels. This protocol was chosen to assess lactate based upon the recommendations of previous research (17,18).

The CPK, LDH, and AST assays were performed with colorimetric procedures, while lactate was assessed via a YSI # 28 lactate analyzer. Urinary ketones were assessed with Ames multi-stix reagent strips, and concentrations assessed colorimetrically (12).

Environmental Conditions: Testing was conducted before (pre-test) and immediately after (post-test) 96-120 h MFOs on four separate occasions with different environmental conditions: 1) sea level, neutral temperatures (n=14); 2) sea level, cold temperatures (n=16); 3) moderate altitude, neutral temperatures (n=16); and 4) moderate altitude, cold temperatures (n=16 [see Table 2 for MFO locations and environmental conditions]). Each MFO consisted of marches, rock climbing, and infantry combat maneuvers. During the operations, subjects carried packs, a weapon, and wore clothing which collectively weighed 20-25 kg. During the MFOs the subjects consumed military field rations (MREs) "ad libium," with their total daily caloric intake being approximately 3800 kilocalories.

Field Procedures: The tests administered as well as the testing protocols remained constant throughout each study location. The pre-MFO session took place on the day (AM) of deployment. The post-MFO session was

conducted immediately upon the subjects returning from the field as close to the same time of day as the pre-MFO session as possible. For the post-MFO session the subjects were prevented from eating or drinking until the testing session was completed. Both testing sessions took place while subjects were in the post-absorptive state (~4-7 hours). The testing for the cold experimental trials were conducted in a sheltered area which was climate controlled.

TABLE 2. Site Locations and Environmental Conditions at Which the Testing Trials Were Conducted

	Neutral Moderate Altitude	Cold Moderate Altitude	Cold Sea Level	Neutral Sea Level
Location:	MWTC Bridgeport, CA	MWTC Bridgeport, CA	Fort McCoy Sparta, WI	Camp Pendleton Oceanside, CA
Altitude:	2100-2900 M	2100-2900 M	sea level	sea level
Weather:	moderate 10°C - 30°C partly cloudy light rain	cold -22°C - -2°C partly cloudy light snow	cold -15°C - 3°C cloudy light snow	moderate 15°C - 32°C partly cloudy no precipitation
Operations:	4.5 days simulated combat maneuvers	4 days training exercises	4.5 days simulated combat maneuvers	4 days simulated combat maneuvers

MWTC = Mountain Warfare Training Center (U.S.M.C.)

Statistical Analysis: Statistical analyses revealed no significant effects due to moderate altitude exposure on performance measures. Therefore, subsequent discussion is directed toward the cold (CO; n=32), and non-cold (NC; n=30) treatment comparison only. A 2 x 2 between-within ANOVA was used to examine for environmental condition (CO vs NC) and time (pre-post MFO) effects for all measures except urinary ketones. Urinary ketones were assessed with a non-parametric ANOVA. Post hoc comparison of means (Fisher LSD and Ryan's) were used to determine main or interaction effects where appropriate. Alpha levels were set at $p \leq 0.05$.

RESULTS

Wingate Performance: All absolute and relative anaerobic power results from the Wingate test are shown in Figures 1 and 2. MFO significantly ($p \leq 0.01$) reduced (pre-post, combined overall effects) absolute mean (5.4%) and peak power (4.5%). Significant ($p \leq 0.05$) decreases were also observed for relative mean and peak power pre-post MFO. However, the reductions in relative measures were greater under C conditions for mean power (9.8%) and peak power (8.4%), as compared to NC mean and peak power (3.1% and 1.6%, respectively). No significant effects were observed for the fatigue index (pre-MFO = 54.2 ± 1.9 vs 50.5 ± 1.1, post-MFO = 51.5 ± 1.2 vs 48.7 ± 1.8 for C and NC, respectively).

Muscular Performance: The results of the muscle strength tests are reported in Table 3. No significant changes in left-right handgrip or push-ups were observed due to environmental conditions, MFO, or their interaction.

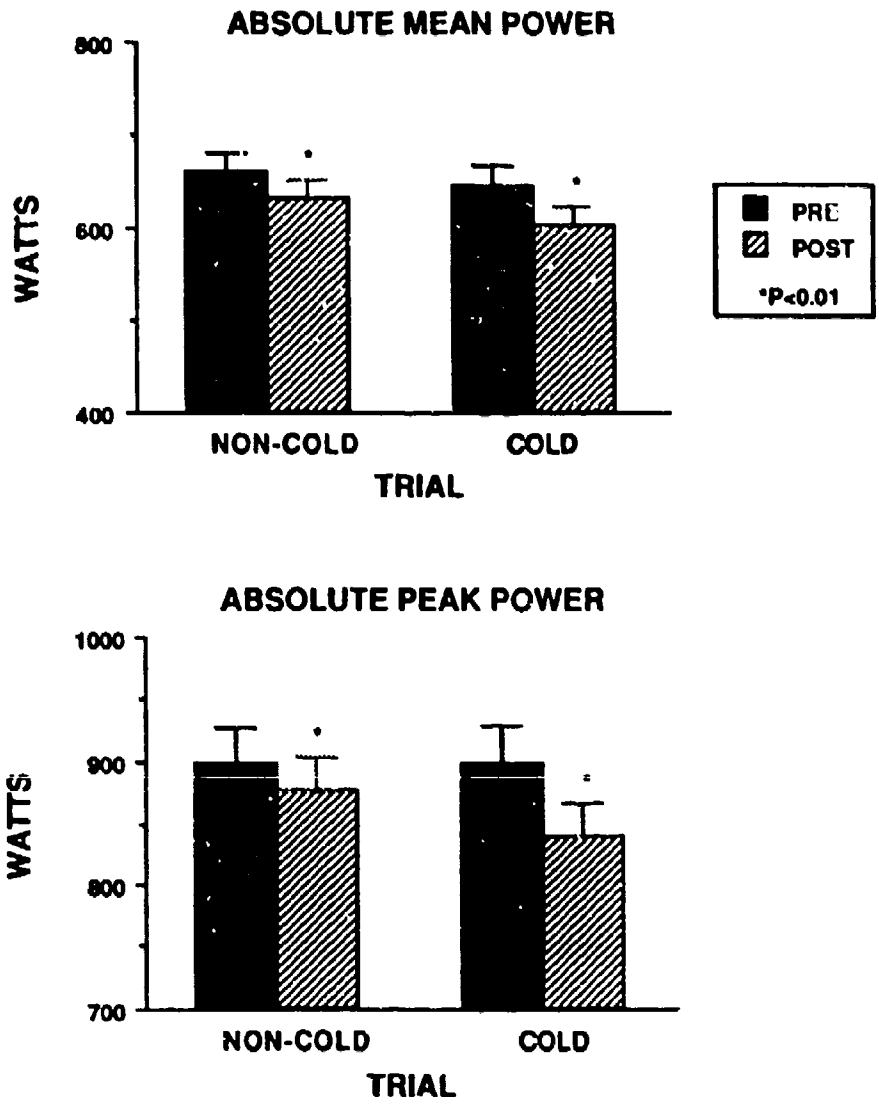

FIGURE 1. Absolute mean and peak power changes from the Wingate test pre- and post- the military field operations. An * indicates that a significant change from pre-MFO levels has occurred.

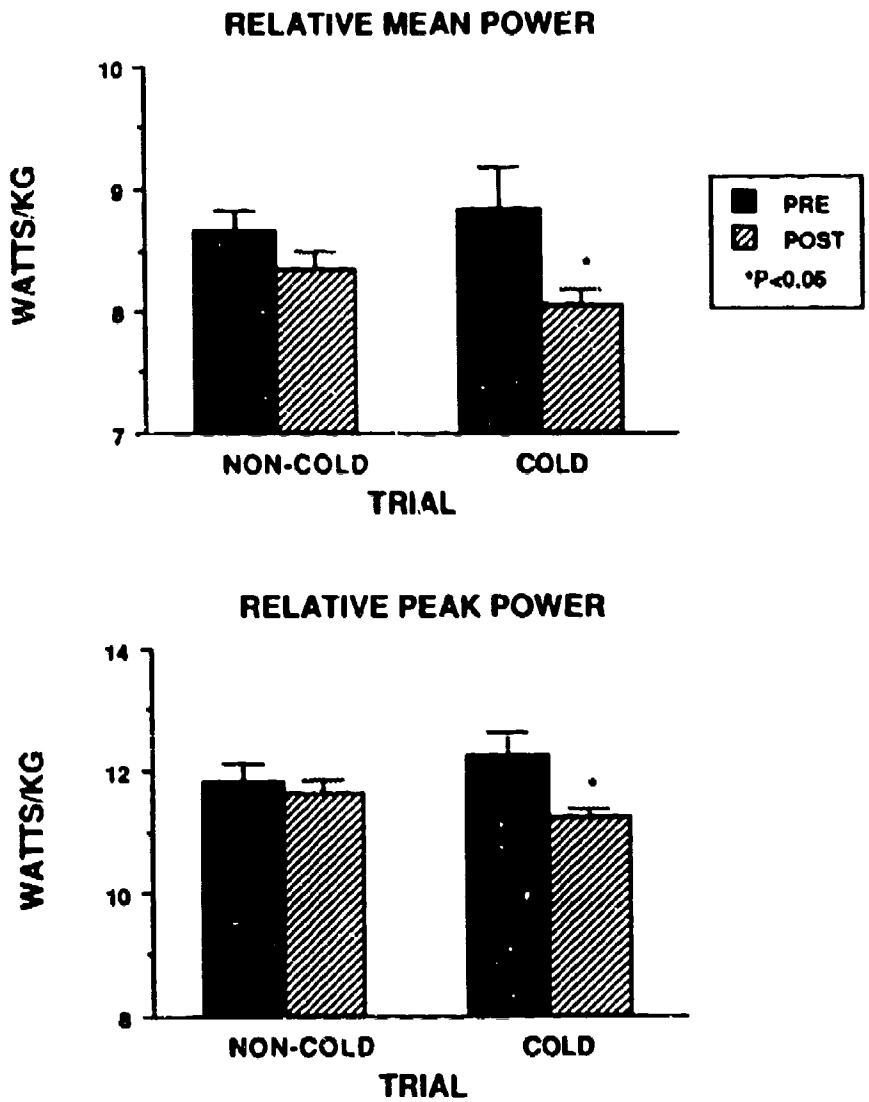

FIGURE 2. Relative mean and peak power changes from the Wingate test pre- and post- the military field operations. An * indicates that a significant change from pre-MFO levels has occurred.

TABLE 3. Push-up and Sit-up Results (X±SE)

Measure	Condition	Pre-MFO	Post-MFO
Hand Grip (kg)			
Left	CO	42.4±8.2	41.8±6.9
	NC	51.8±8.3	52.4±6.9
Right	CO	44.6±6.0	43.7±6.0
	NC	54.2±7.0	55.0±5.8
Push-up (no/2 min)			
	CO	44.2±13.7	43.4±10.1
	NC	55.1±14.0	56.4±18.1

Blood and Urine Measures: Serum enzymes were significantly elevated due to the MFO (see Figure 3); however, the increases were greater in the C than NC for both CPK (156.5% vs -7.2%, respectively), and AST (43.4% vs 1.0%, respectively). The LDH levels of the subjects were significantly higher (18.5% and 12.6%) after the MFOs in both the CO and NC.

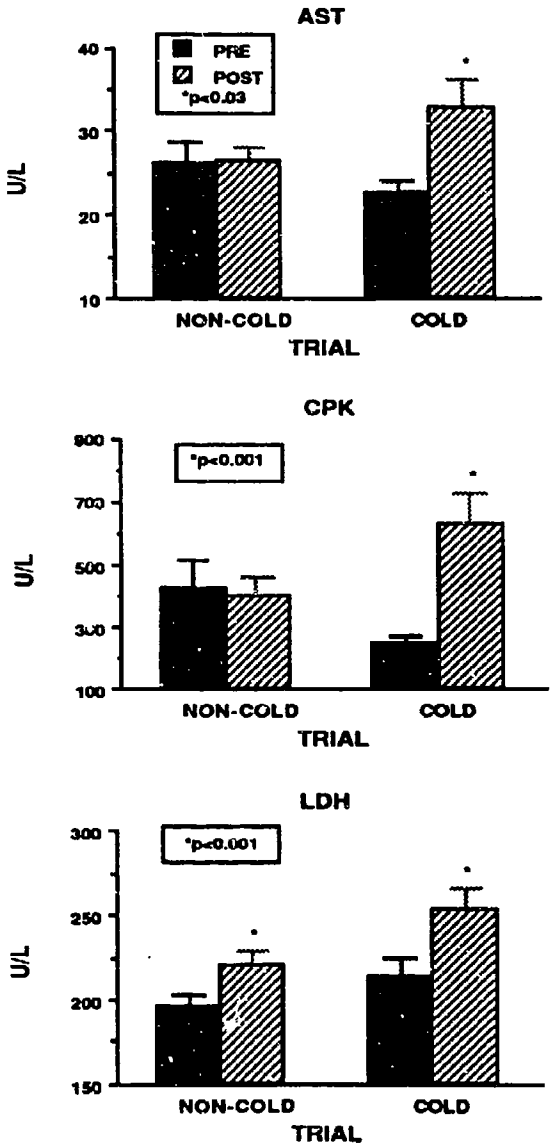

FIGURE 3. Resting serum enzyme results pre- and post- military field operations. Top panel - aspartate aminotransferase (AST), middle panel - creatine phosphokinase (CPK), bottom panel - lactate dehydrogenase (LDH). An * indicates that a significant change from pre-MFO levels has occurred.

Submaximal exercise before and after the MFO produced a significant elevation in blood lactate levels (see Figure 4). However, there was a significant ($p<0.01$) decrease in exercise lactate values post-MFO at the same absolute workload for both conditions (declines of 26.8% and 24.6% for CO and NC, respectively).

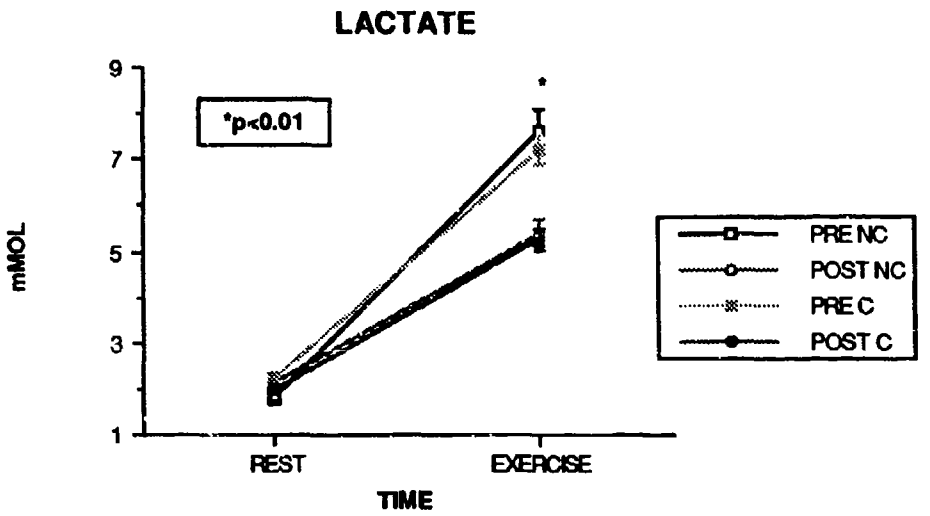

FIGURE 4. Blood lactate changes from rest to 240 W of exercise pre- and post- the military field operations. An * indicates that a significant change from pre-MFO exercise lactate levels has occurred.

Prior to the MFO, only a few subjects showed positive traces of urinary ketones in both the CO and NC condition. The MFO resulted in increased ketone concentrations in the CO and NC (see Figure 5), however, the increase was significant ($p<0.01$) only in the CO condition ($1077\pm309\%$ vs $288\pm101\%$ for CO and NC, respectively).

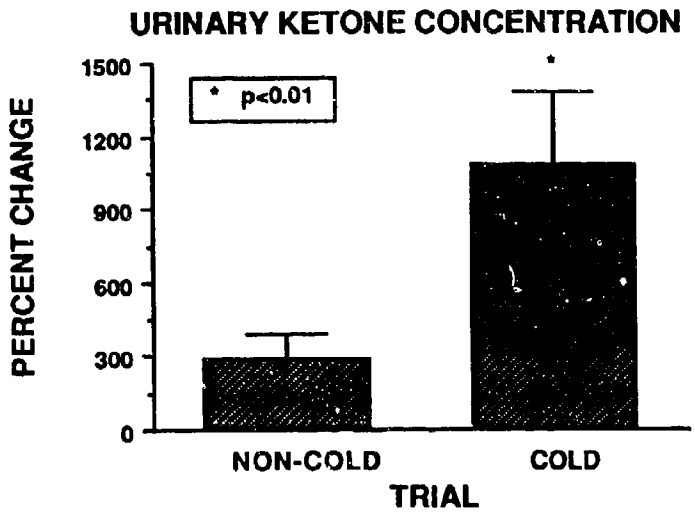

FIGURE 5. Urinary ketone concentration changes post military field operations. An * indicates that a significant between group difference exist.

DISCUSSION

Anaerobic Power: Previous research would imply that cold exposure and MFO should each separately produce significant anaerobic power decrements in humans (10,14). In the present study, results from the absolute measures suggest that a 96-120 h MFO is likely to produce significant reductions in anaerobic power regardless of environment. Analyses of relative measures, however, indicate there is a interactive effect between MFO and environmental conditions. That is, a MFO conducted in cold weather promotes reductions in relative anaerobic power greater than in a non-cold environment.

Physiologically, the reductions in mean and peak power observed could have occurred for several reasons: 1) substrate inavailability (i.e.,

decreased ATP-PC and/or glucose-glycogen levels), 2) enzymatic impairment due to muscle tissue damage, 3) buffering insufficiency, and/or 4) dehydration. The first mechanism seems probable due to the physical demands and evaluated metabolic cost of the MFO. Increased physical workloads can severely compromise carbohydrate (CHO) stores in the body (17,25). Additionally, the typical physiological adaptations to prolonged cold exposure (e.g., shivering, catecholamine elevations) place even greater demands on the body's available CHO (1,19). If CHO stores are compromised, a state of enhanced fat metabolism can develop (10,25). In the present study this possibility is supported by elevated resting urinary ketones, especially in the CO environment, in the subjects after the MFO. Additionally, submaximal exercise lactate levels were significantly lower after the MFO in both conditions. This latter finding in light of the fact that the subjects performed comparable workloads (pre-post MFO) suggests a limited glucose/glycogen substrate availability (20). Collectively, these metabolic data (ketones and lactate) imply a CHO deficient state existed; that is, muscle glucose and glycogen levels (anaerobic glycolysis substrate) may have been compromised, and this effect seems more so in the cold environment.

Of importance to note is that our lactate changes may have been influenced by the altitude aspect of our environmental conditions. West has shown exercise lactate elevations are reduced at altitude for reasons that are not entirely clear (24). However, in this study exactly comparable altitude exposures occurred in the CO and NC conditions; and the magnitude of the altitude effect on exercise lactate was nearly identical. Thus, the influence of altitude on our results was balanced across the experimental conditions.

The second possibility proposed also seems a likely explanation for the current results. The serum CPK and AST enzymes, markers of tissue damage and disrupted cellular homeostasis, were elevated following the MFO, especially in the cold in nearly all subjects (22). However, these enzymatic measures are very general and indirect in nature, suggesting a need for more direct measures (e.g., muscle tissue samples) would confirm whether the damage encountered would directly impair anaerobic metabolic pathways.

The third possibility (buffering insufficiency), while a potential mechanism, is not altogether supported by the present data. The Wingate is only 30 seconds in duration, therefore, evidence of buffering insufficiency would be expected in the latter stages of the test (i.e., significant decreases in power output) (27). This was not the case as the fatigue index results suggested no apparent change due to MFO or environmental condition. Additionally, the decreased ability to buffer H^+ ions during short-term maximal work would be expected at the moderate altitude trials (21). This was not the case, as no statistically significant differences in anaerobic performance were found due to moderate altitude exposure.

The final mechanism, dehydration, has been proposed as a detrimental factor to anaerobic performance (6). There is some debate as to what percentage of body weight loss due to dehydration will affect performance. Most reports suggest a 4-5% decrease in body weight is necessary in order for dehydration to be considered a salient factor in performance (3,6,25). If the weight lost by the subjects of the present study was due entirely to dehydration, it would represent only -2% of

their body weight, which would suggest the effects of dehydration on decreased anaerobic power post MFO was minimal.

Interpreting the present data relative to the cold environmental effects is difficult. The question remains as to whether the subjects were actually cold or only exposed to the cold. It is certain that the present CO subjects lived (field tents) and worked in moderately severe cold conditions during the MFO. Nevertheless, this does not necessarily mean that they were cold due to precautionary measures (i.e., clothing, activity, surroundings). Therefore, it is uncertain whether the observed changes were a function of the physiological adaptations to the cold environment, or the increased workload encountered in working in the cold. The investigators observed there was a tremendous inefficiency in the performance of daily tasks by the CO subjects in the snow. This was compounded by a lack of skill in basic winter locomotor tasks, such as skiing and snowshoeing, thereby increasing the metabolic demands and energy requirements in the cold. Most likely, the increased workload and adaptation acted synergistically to induce the effects observed.

Muscular Strength and Endurance: These results were somewhat unexpected and suggest there was a lack of a treatment effect, or an insensitivity in the measures chosen. The lack of a treatment effect does not agree with existing research. Both cold exposure and extended physical demands, such as encountered during MFO, have been shown to compromise muscle function (7,10). However, high initial levels of physical fitness attenuate the degree of muscle function compromised under such conditions (10,19). This may explain the current results since the subjects were in good physical condition at the onset of the study. Whether our measures were sensitive enough to detect a change in muscle

function is debatable. The tests chosen are "gross" indicators of muscle strength performance capacity; however, they are very applicable performance tasks relative to what is expected of a U. S. Marine in the field. Therefore, changes detected with these tests do have a face validity relative to their sensitivity.

In Summary: The Wingate test results suggest that anaerobic power is compromised after an MFO; however, the degree of reduction is augment in a cold environment when power is expressed relative to body weight. The changes in relative power output could not be attributable to differences in body weight as weigh changes after MFO were comparable between CO and NC conditions. Physiologically, the explanation for the reductions in anaerobic performance observed is not fully clear. But, blood-urine results suggest tissue damage, and substrate unavailability may be major contributors to the effect. No significant changes in the muscular strength-endurance measures suggest that neither the environmental conditions or the MFO were highly taxing on the these physiological parameters or that the subjects were well suited for the demands placed upon them.

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NHRC Report No. 90-18	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Health Research Center 6b. OFFICE SYMBOL (If applicable) Code 10	7a. NAME OF MONITORING ORGANIZATION Chief, Bureau of Medicine & Surgery
6c. ADDRESS (City, State, and ZIP Code) P. O. Box 85122 San Diego, CA 92186-5122	7b. ADDRESS (City, State, and ZIP Code) Department of the Navy Washington, D.C. 20372
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Medical Research & Develop. Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Naval Medical Command National Capitol Region Bethesda, MD 20814-5044	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 63706N PROJECT NO. MR04101.07 TASK NO 6004 WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) (U) Military Operations in the Cold: Effects on Anaerobic-Muscular Performance and Select Blood Indices	
12 PERSONAL AUTHOR(S) Hackney, A.C.; Shaw, J.M.; Hodgdon, J.A.; Coyne, J.T.; Kelleher, D.L.	
13a. TYPE OF REPORT Final 13b TIME COVERED FROM _____ TO _____ 14. DATE OF REPORT (Year, Month, Day) 1990 September 13 15 PAGE COUNT 23	
16. SUPPLEMENTARY NOTATION	
17 COSATI CODES FIELD / GROUP / SUB-GROUP	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) cold, anaerobic performance, wingate, military field operations

19. ABSTRACT (Continue on reverse if necessary and identify by block number) This study examined the effects of military field operations (MFO) under different environmental conditions on anaerobic performance (ANP). U.S. Marines were tested in the field under the following conditions: 1) non-cold environment (NC; n=30, 10 to 32°C), and 2) a cold environment (CO; n=32, -2 to -22°C). Subjects performed 30 sec Wingate tests (WIN), 2 min push-ups, and hand-grip strength pre- and immediately post-MFO to assess ANP. The MFO consisted of ~4.5 days of combat training maneuvers while carrying field equipment (packs and weapon, ~25 kg). WIN measures obtained were absolute and relative mean power (MP), 5 sec peak power (PP), and fatigue index (FI; % decline). Significant main effects ($p<0.01$) were observed for time (pre-post MFO). Reductions occurred in absolute MP (651.8 ± 30.3 to 616.4 ± 28.5 W; X ± SE) and PP (897.8 ± 41.6 to 857.0 ± 39.1 W); however, no effect on FI was seen. Significant interaction effects ($p<0.05$) were observed in relative measures. Reductions (pre-post) in MP (NC=8.64 ± 0.16 to 8.37 ± 0.14 W/kg; CO=8.91 ± 0.26 to 8.04 ± 0.15 W/kg) and PP (NC=11.80 ± 0.24 to 11.61 ± 0.33 W/kg; CO=12.23 ± 0.35 to 11.20 ± 0.19 W/kg) were greater under CO than NC conditions. These (cont)

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