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November 1981

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PHYSICAL PERFORMANCE TASKS REQUIRED OF UNITED STATES MARINES OPERATING IN A DESERT ENVIRONMENT

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ABSTRACT

Nine representatives of the Institute of Human Performance were integrated into a marine battalion during a CAX (combined arms exercise) for the purpose of gathering descriptive and objective information regarding the nature and types of physical performance tasks encountered by marine infantrymen (MOS 0311) during desert combat.

Through the use of minicassette recorders, scales, cameras and other data collection equipment, scenarios were described which typify the critical, frequent and strenous types of tasks indigenous to marines in this environment.

Distances covered on foot, loads carried, rates of travel and grades encountered are detailed and described as well as other environmental overlays which impact on troop performance.

It was determined that for the most part, a mechanized, motorized combat scenario does not require high levels of physical ability; however, fire team rushes represent a critical scenario, with high levels of aerobic and anaerobic power, particularly when performed in ambient temperatures of 100-107^{o}F.

A taxonomy of physical tasks from this environment will be added to physical performance data from other Marine Corps theaters of operations for the purpose of developing a complete job analysis of activities involving strength and endurance factors.

SECTION 1.0: INTRODUCTION

1.1 Study Purpose

The purpose of this work was to gather descriptive and objective information regarding the physical performance tasks required of United States Marines with the MOS 0311 (rifleman) in a desert combat theater of operations. This information will serve as the foundation of a job analysis leading to the development of a job-related physical performance examination capable of predicting combat readiness of marines faced with the prospects of action in different environments.

1.2 Background

Headquarters, USMC (Code TRI) has the responsibility for the administration of the currently used Physical Fitness Test (PFT). This test has been in existence for nine years and represents a fitness battery consisting of items whose capability of predicting combat readiness has not been scientifically validated. The test battery consists of pull-ups, sit-ups and a three-mile run [1].

Scoring the fitness battery is arbitrary, and does not take into account such factors as environment, loads carried or numerous other factors that will no doubt have a profound impact on combat capabilities and readiness. Once again, the relationship between combat performance and scores on the PFT has neither been investigated nor established on the basis of any empirical work.

Noting these shortcomings, representatives of HQMC approached the Institute of Human Performance regarding the possibility of improving upon the validity of the PFT and/or the addition of other measures that might allow the battalion commander to have a definitive picture of the combat readiness of his troops. In view of the Navy's responsibility for research of this type, meetings were held with representatives of the Naval Medical Research and Development Command to discuss the research design necessary to accomplish the stated objectives of this project.

A review of the literature and information regarding the job description of the rifleman and/or infantryman quickly revealed that aside from only broad, sweeping statements of purpose there exists no empirical data describing the physical performance tasks necessary to accomplish the intended objectives of this speciality. Since any test development must start with a well-planned and carefully constructed job analysis, it was decided that such an analysis should be made.

1.3 Related Studies

Many of the military occupations for which standards have been developed are non-combat in nature, and are therefore not useful in development of a physical performance test for the Marine Corps. Dealing with the Marine Corps does have a number of advantages in that the Corps believes that every marine is fundamentally a rifleman, and as such, only one minimum set of standards will need to be developed for the entire Corps. Since the Marine Corps' mission involves combat under a number of environmental extremes, gathering information on physical performance in a variety of combat environments (desert, cold, tropical and amphibious) is an integral part of the data collection process.

Testing for physical fitness and combat readiness probably had its origins in ancient Greece. The first data collected involving an empirical analysis of modern military tasks was probably collected by Brezina and

Kolmer in 1912 [2]. In a classic 1923 study by Cathcart, Richardson and Campbell of the Royal Army, it was noted that "the heavier loads were a distinct menace to the maintenance of normal cardiac activity" [3].

A review of military and civilian job analysis methods revealed that a number of options existed which would comply with the Uniform Guidelines on Employee Selection Procedures.[4] These guidelines represent the concensus of those federal agencies (Departments of Labor, Office of Personnel Management, Equal Employment Opportunity Commission, Department of Justice and Department of the Treasury) that deal with the methods and procedures for the validation and development of pre-employment tests. Such guidelines would best serve the Navy and the Marine Corps in the production of new validated standards.

The Army, through the Research Institute of Environmental Medicine (USARIEM), conducted a survey of physical tasks, and then categorized the MOS's surveyed according to the most strenuous physical tasks within each MOS. On the basis of their findings[5], job demands were then sorted into five clusters. The major purpose of this work was to develop a screening device to be used at the AFEES centers, and not as a tool to predict combat readiness.

USARIEM has conducted an analysis of energy expenditure of soldiers involved in combat operations in a tropical environment. This work by Goldman[6] found the upper limits of energy expenditure to be in the range of 400 to 450 kcal per hour. Total weight carried represented the most critical factor in the energy output, while terrain was independently related to energy requirements if the troops were allowed to work at their own pace.

Job analyses and on going research conducted by the Navy[7] and the

Air Force[8] have little applicability, except that onsite observation and measurement are currently being employed to assess physical performance.

It is interesting to note the trend towards on-the-job measurement, as opposed to pencil and paper job analysis. With the increased capability associated with portable metabolic measurement equipment and other micro-electronic measurement equipment, old methods of data collection are rapidly being replaced.

Observation and measurement by trained exercise physiologists represent the optimum method of gathering the types of data needed to construct a taxonomy of physical performance tasks. Individual interview and observation have been demonstrated as the most reliable methods of gathering information regarding the specific dimensions of a physical job[9]. Clearly, obtaining reliable data on the physical tasks of marines through some method other than onsite observation represents a less than preferred approach. To perform the work described below, a team of nine observers was selected. These observers had an academic background in exercise physiology, work physiology or physical education, with extensive experience in the areas of tests and measurements of physical performance. Two members of the team had doctoral degrees, while five members had masters degrees.

SECTION 2.0: METHODOLOGY

Section 2.0 describes the action plan used to accomplish the stated purpose of this project. Figure 2.1 displays the sequence of project tasks and the order in which they were accomplished.

2.1 Site Selection

A series of meetings was held between staff members of IHP and representatives of Headquarters Marine Corps (Code TRI). As a result of these meetings it was determined that observations and data collection would be conducted at the Combined Arms Combat Center (CACC) at Twentynine Palms, California.

The CACC is a base encompassing 932 square miles in the southern Mojave Desert. This area is classified as having an arid upland desert climate. Summer months are characterized by high temperatures, low humidity, and clear days. While the average annual temperature is 67 °F, the temperature occasionally reaches 130 °F in the summer. Relative annual humidity is approximately 27% but ranges between 2% and 69%. Average annual precipitation is 4 inches, most of which occurs as rain from July to January. The terrain consists of steep sloped, highly eroded mountains, that gently slope to flat intermediate valleys. The valleys are oriented northwest to southeast. Geographic relief is moderate with elevations ranging from 1,800 to 4,500 feet. Most mountain segments have approximately 2,000 feet of relief between the valley floor and summit. The combat center also contains several dune areas, lava flow, and dry lakes. The CACC area is typical of many other desert environments around the world [10].

2.2 Battalion Selection

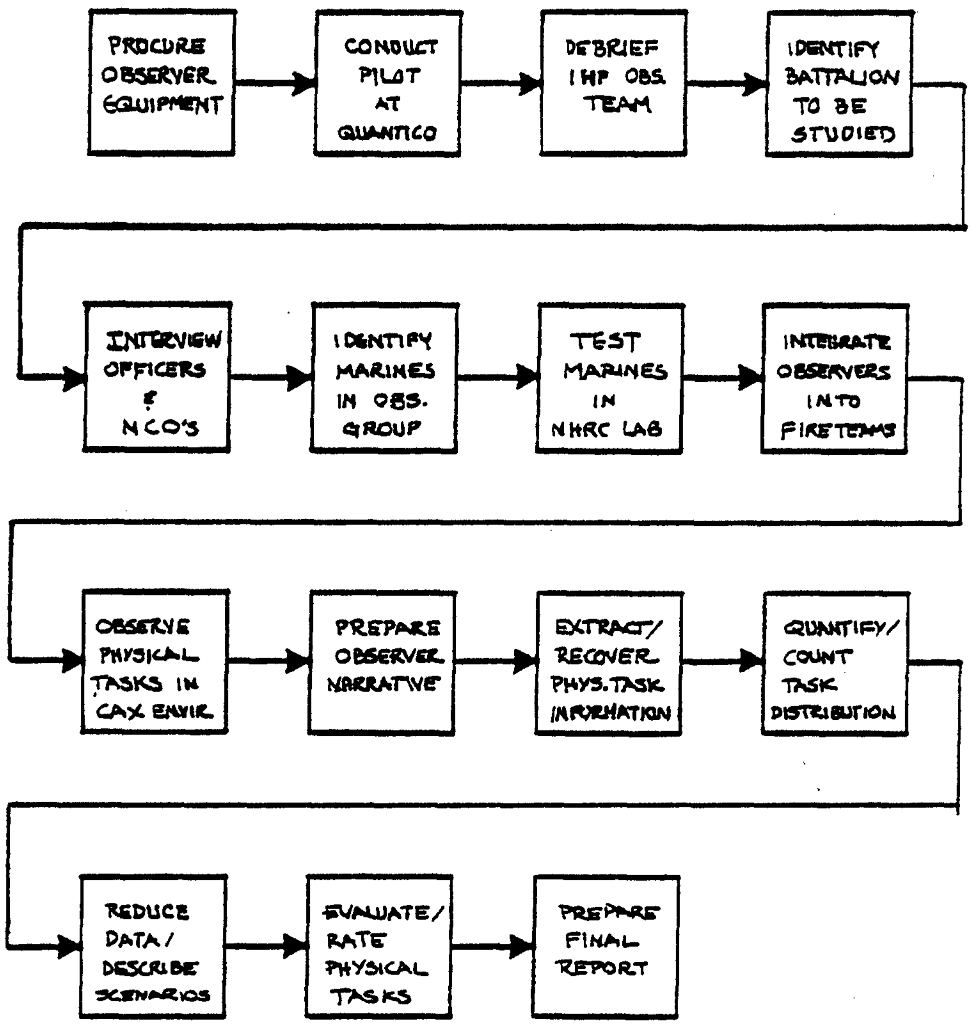
During the same series of meetings with HQMC it was determined that the 2nd Battalion, 2nd Marine Regiment, 2nd Marine Division was scheduled for training at the Combined Arms Combat Center in June and July of 1980. This training sequence was to culminate with a Combined Arms Exercise (CAX). It was thus determined that the team would observe the battalion during the CAX. It was felt that the CAX would realistically simulate desert combat conditions. Live fire would be used throughout the tactical evolution.

2.3 Liason with 2nd Battalion, 2nd Marines

Shortly after the battalion selection, two members of the IHP observation team were dispatched to Camp LeJeune, North Carolina to make contact with the 2nd Battalion, 2nd Marines. The commissioned and non-commission officers of the battalion were briefed as to the purpose of the project. They were also asked to select 20 marines as subjects for the observation pool, out of which 18 would be observed. It was specified that the subjects should be working in the military occupational speciality MOS 0311. Each rifle platoon in the battalion was requested to provide subjects, with not more than one subject from a single squad. This request was made to provide the observation team with exposure to the wide variety of combat tasks that would occur during the CAX because different platoons would be functioning as helo (helicopter borne), motorized, or mechanized units. Finally, the commissioned and non-commissioned officers were informed that the marines selected should be those whom they would prefer to have in their command in a combat situation.

Using these selection standards, the commissioned and non-commissioned officers selected the subjects and asked them to report to the observation team. Once the subjects were identified, they were administered the marine

Figure 2.1



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Corp's physical fitness test (PFT). A more definitive evaluation of the subjects would take place later at NHRC (Naval Health Research Center) in San Diego.

2.4 (NHRC) Participation

Following subject selection and the establishment of CAX observation dates, IHP contacted NHRC to determine the availability of physical fitness assessment facilities. The experimental design called for the development of physiological profiles of the 18 individual marines who were to be observed during the CAX. NHRC agreed to conduct this physiological evaluation of the subjects, and also provided IHP with the services of a staff physiologist to serve as a member of the observation team.

2.5 Observation Team Training

Several meetings were conducted with the members of the observation team to familiarize the team members with the desert environment and CAX conditions and to develop standardized methods for data collection.

2.5.1 Preliminary Work at Quantico, Virginia

All equipment and observation techniques were tested initially at the Marine Corps Base in Quantico, Virginia during a simulated combat training operation. Each observer was assigned to a subject in an aggressor unit. All physical activity during a combat problem was recorded for a period of nine hours. This allowed the observation team members to learn how to use the data recording equipment while moving, and become acquainted with the routine activities of the marine rifleman.

Several days after this preliminary operation, a meeting was held with the observation team members to evaluate the activities at Quantico. This evaluation of the data collection/recording methods indicated that weighing of loads and note-taking would have to be accomplished largely during periods of subject inactivity. Once the subject began to move, the tape recorder would serve as the most practical instrument for data collection.

2.5.2 Recording and Reporting Categories

Standardized methods for reporting observations were developed. Speeds for movement by foot were to be classified as:

Slow Walk	(1 - 2.0 mph)
Fast Walk	(2.1 - 3.4 mph)
Slow Run	(3.5 - 4.4 mph)
Fast Run	(4.5 mph or greater)

Grades were to be recorded in degrees of inclination. The specific sequence to be used in recording data is given in Table 2.1.

TABLE 2.1

DATA ENTRY SYSTEM FOR TAPE RECORDERS

BEGIN TAPE:

1. Observer
2. Date
3. Time
4. Tape #

TABLE 2.1 (continued)

RECORD:

1. Distances
2. Speeds
3. Grade
4. Body Position
5. External Loads
6. Footing
7. Obstacles

As a result of this preliminary work it was decided that the observer team would wear the utility uniform of the marines, and integrate with the battalion as fire team members. This was done to minimize interference with the normal flow of the combat problem. Body armor and helmets would also be worn by the observers for protection from live fire.

2.6 Data Collection/Recording Equipment

All data collection/recording equipment was selected based upon function and durability while exposed to dry heat and sand. Each team member was issued a tape recorder (Norelco 185 minicassette) for recording descriptive information, a camera (Olympus XA) to document the task, a 25 Kg capacity scale (Chatillon IN-50) in 250 gram gradients to weigh articles carried by subjects, and a stop watch (Cronus Digital) for recording the elapsed time of physical tasks. Figure 2.2 depicts the equipment carried and used by each observer.

Six Actographs were provided by the Department of Military Medical Psychophysiology, Walter Reed Army Institute of Research. These were used to provide a quantitative measure of gross body movement. Three members of the observation team were also provided with Holter monitors (Avionics Model 445). These were used to continuously monitor the heart rates of selected subjects. One team member was issued a mercury thermometer with a temperature range of -50°F to 120°F. Temperature measurements were recorded hourly throughout the three-day exercise.

2.7 Physiological Testing at NHRC

After approximately two weeks of desert training at Twentynine Palms, the 18 subjects from the battalion were transported by helicopter to NHRC where they were met by the NHRC and IHP research team. Physical fitness evaluation of the subjects was conducted over a two-day period. During this time the subjects were housed at the Marine Corps' Recruit Depot and shuttled by van to NHRC as required. Upon arrival, each subject was briefed by an IHP investigator about the evaluation techniques to be used.

2.7.1 Determination of Percent Body Fat

Each subject was weighed, and his height determined. Skinfold measurements were taken using a Harpenden skinfold caliper. Skinfold sites included the subscapula, triceps, biceps, pectoralis, and suprailiac. Neck and abdominal circumferences were obtained using a Gulick tape measure. Percent fat was estimated using the formula of Wright, Dotson and Davis (11).

2.7.2 Resting Blood Pressure and EKG

Resting blood pressure was measured in the supine position. A resting, 12 lead EKG was also obtained. Resting heart rate was measured directly from the resting EKG.

2.7.3 Aerobic Fitness Assessment

Maximum O_2 uptake was measured using a treadmill protocol developed by Dr. James Hodgedon of NHRC. All tests were performed using a Quinton Model 18-60 treadmill. Marines were instructed to exert themselves maximally. Expiratory gas analysis was performed and results were computed on line using a Hewlett Packard Computing system (see figure 2.3). This technique allowed for constant monitoring of the Respiratory Exchange Ratio and a determination of the level of effort expended. Blood pressure was monitored during the exercise test. Heart rate and EKG were continuously monitored during the entire procedure.

2.7.4 Neuromuscular Fitness Assessment

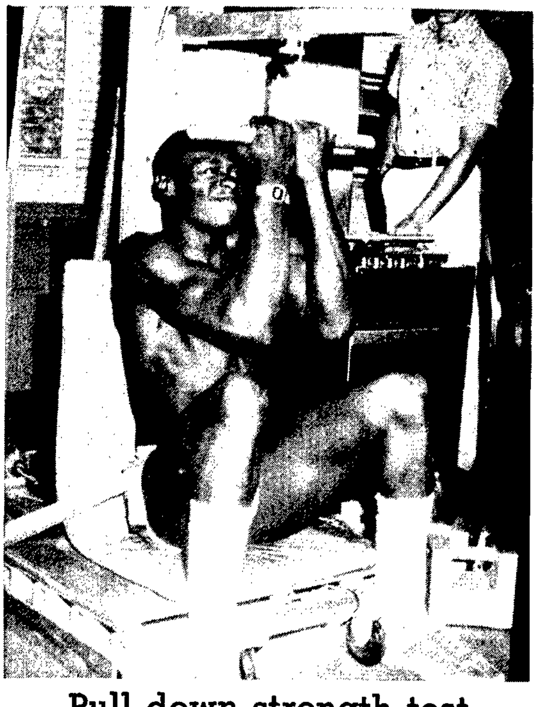
The final evaluation phase consisted of a series of neuromuscular tests for muscular power and strength. Muscular power, defined as the ability to exert maximum force in a specified time, was estimated in the legs using the standing long jump. The best single score for three jumps was recorded. Muscular strength was evaluated by measuring grip strength and static arm strength. Grip strength was measured for right hand and left hand using a Lafayette hand-dynamometer. Each subject was allowed three efforts per hand with the highest value for each hand being recorded. Static arm strength, or shoulder girdle strength, was measured with a force chain designed by the USARIEM. The subject was strapped in a seat and instructed to grip (pronated) a suspended bar in front of him. The bar was then adjusted to bring the subject's elbows to a 90° angle, with the humerus parallel to the floor (see figure 2.3). Once the adjustment was completed, the subject was asked to pull downward on the bar with maximum force. As with grip strength, each subject was allowed three efforts and the highest value was recorded. A Muscular Strength Index score was obtained by summing both left and right grip strength scores and the static arm strength score. Following the completion of this evaluation, the IHP observation team and the marine subjects were transported by helicopter from San Diego to Twentynine Palms.

2.8 Observation at Twentynine Palms

The training schedule at the CACC allowed the marines to acclimatize over a period of two weeks to the desert environment while learning desert tactics and survival. The final three days of the schedule had been reserved for a simulated combat exercise that would provide the marines with an opportunity to apply the knowledge that they had gained. The observation team was briefed by battalion officers on the plans for the three-day combat exercise. One rifle company had been designated as a helolift unit with the primary means of transportation being helicopters (CH-46's and CH-53's, see figure 2.6). One company would be transported by mechanized vehicles, (Amtraks, figure 2.9). The third company would be motorized using T-35 trucks (figure 2.8) and Gamma Goats (figure 2.7). The battalion would be receiving artillery and air support as it moved along a 40km course called the Delta Corridor. The corridor presented a series of "enemy" bunkers mostly situated on high ground. These bunkers were to be assaulted by the marines. One company would be held in reserve, while the other two "leap-frogged" up the corridor in the assault. Because magnetic fields were hampering electronic communications in the desert, the "commence firing" and "cease firing" signals between platoons were conveyed with smoke grenades (yellow for commence, green for cease-fire). The briefing session was ended with a reminder to the officers and observation team that this would be a live fire exercise.

Data gathering equipment
fig. 2.2

Maximum oxygen uptake test
fig. 2.3



Pull down strength test
fig. 2.4

Observer weighing equipment
fig. 2.5

Once the three-day exercise was explained, it was decided that one member of the observation team would act as a liaison, and nine members would be assigned two subjects each. A subject would be observed for 36 hours, and then the observation team member would switch to his second subject for the final 36 hours. Each observer was assigned two subjects from the same platoon. After the assignments were made, the observation team members were to meet with the platoon commander for further briefings. The platoon commanders were informed that the observation team members were to be considered as part of their fire team.

The observation team members were then transported from the field (Camp Wilson) to the main base of Twentynine Palms where they were issued "782" gear, consisting of steel helmets, helmet liners, body armor, All-Purpose Light-Weight Individual Carrying Equipment (i.e. the ALICE field pack), sleeping bags, canteens, canteen cups, web belt and suspenders, ammunition pouches, and gas masks. Figure 2.10 depicts a marine wearing this load. The commanding officer of the CACC requested that the observers be identifiable, so white tape was used to form a cross on the backs of the observer's body armor.

The observers were returned to the field in the afternoon preceeding the first day of the CAX. This allowed them to locate their first subject and to be transported out with the subject's platoon as it moved into position. At this point each observer was, for all intents and purposes, geographically isolated from the rest of the observation team.

The first day of the exercise began with the observer weighing and recording the gear carried by the subjects (see figure 2.5). The actograph was activated and the time was noted. Holter monitors were set up by affixing electrodes to the subject's chest using wide micropore tape. The cable was passed over the shoulder and down the back to the monitor which

CH46 helicopter
fig. 2.6

Gamma goat
fig. 2.7

T35 truck
fig. 2.8

Armored personnel carrier
fig. 2.9

Typical Marine load
fig. 2.10

Subject with Holter monitor
fig. 2.11

Building defensive positions
fig. 2.12

Firing light anti-tank weapon (LAW)
fig. 2.13

was located on a waist belt (see figure 2.11). After the proper connections had been made, the monitor was activated, taped shut, and the time was noted.

As the subject engaged in the exercise activities, the observer followed, maintaining close visual contact at all times. All movement, load or gear changes, and terrain covered by the subject were noted using the minicassette recorder, as well as photographed (see figures 2.12 and 2.13). After 36 hours of almost continuous data recording, the observers removed the actographs and Holter monitors from the first subjects, noting the time of removal. The second subjects were then located, and the actographs and Holter monitors were attached to these subjects. The actographs required little attention other than time and subject number notation. The Holter monitors were supplied with a new magnetic tape, batteries, and reactivated. Once again, for 36 hours the subjects were closely followed and data was recorded.

This close contact was maintained throughout the exercise with only two exceptions. One of the subjects was evacuated from the field with heat stroke. In this case the observer assisted the corpsmen in the evacuation and then returned to the field to collect data on an alternate subject. One of the observers was temporarily removed from the field after an apparent case of heat exhaustion. He recovered quickly and was returned to the field where he resumed monitoring his subject.

At the conclusion of the operation, the observers removed the actographs and Holter monitors from their subjects. The observers were then transported with the marines back to Camp Wilson. The reassembled observation team was then taken to the main base at Twentynine Palms, and the members of the observation team were debriefed.

2.9 Preparation of Observer Reports

During the two weeks following the operation at Twentynine Palms, each observer reviewed his tapes and written notes. All photographs of combat activities were developed. This information was then consolidated by each observer into a written report according to the procedures outlined by Hogan and Bernacki [12].

Following a review of these reports, a series of staff meetings was held at IHP. The purpose of these staff meetings was to jointly discuss the observations and to identify areas of criticality and commonality of tasks. Section 3.0 describes the results of this work.

SECTION 3.0: RESULTS

3.1 PHYSICAL FITNESS TEST RESULTS

The three item Physical Fitness Test (PFT) results, displayed in Table 3.1, show that the marine subjects had attained first class scores on this fitness battery. The average time for completion of the three- mile run represents an average mile pace of just slightly over seven minutes per mile. Even the slowest time of 25:23 (8:24 per mile) is indicative of above average physical fitness.[13] The number of sit-ups performed are well above average when compared to data collected on an age-matched sample of individuals tested at the IHP laboratory facility. Since the method used to measure chin-ups is not comparable to conventional measures, it is difficult to make statements regarding the upper body muscular endurance scores attained on this test.

TABLE 3.1

SUBJECT PFT SCORES

	N	X	Range
3-mile run (min:sec.)	18	21:08	17:30-25:23
Max sit-up (2 min.)	18	73.22	62-90
Pull-ups (max.)	18	15.72	5-20
PFT Score	18	245.61	167-300

3.2 LABORATORY EVALUATION RESULTS

Physical description, body composition and anthropometric data are displayed on Table 3.2. Body composition data show that this marine group was slightly less fat than data reported elsewhere for marine subjects

[14]. Resting measures of heart rate and blood pressure are provided in Table 3.3, while dynamic measures of aerobic fitness are displayed in Table 3.4. Maximum aerobic capacity would be considered high normal for this sample compared to age-matched controls. Neuromuscular fitness indicators are displayed in Table 3.5, and compare favorably with age-matched groups of public safety employees tested with the same protocols at the IHP laboratory (IHP unpublished data). No tests of statistical significance were performed on this small sample.

TABLE 3.2

SUBJECT ANTHROPOMETRIC PROFILE

	N	X	Range
Height (cm)	18	179.27	167.6 - 186.7
Weight (Kg)	18	73.43	57.9 - 91.3
Skinfolds (mm)	18		
a. Subscapular		10.99	7.2 - 17.5
b. Triceps		8.00	5.2 - 15.0
c. Biceps		4.54	3.0 - 7.4
d. Pectoralis		7.32	4.0 - 16.6
e. Suprailiac		13.88	5.5 - 30.0
Circumferences (cm)	18		
a. Neck		36.75	34.0 - 40.0
b. Abdomen		79.94	67.5 - 94.0
Percent Fat (7%)	18	15.06	9.2 - 21.4
Density	18	1.064	1.050 - 1.078
Lean Body Weight (Kg)	18	65.83	51.1 - 76.4

TABLE 3.3

SUBJECT AT REST

	N	40	Range
Resting Heart Rate	17	58.12	48.0 - 80.0
Resting Blood Pressure	18	123/70	100/64 - 140/84

TABLE 3.4

SUBJECT AEROBIC EVALUATION

	N	X	Range
Age (yr.)	18	20.7	19.0 - 26.0
Anaerobic threshold ($ml \cdot kg^{-1} \cdot min^{-1}$)	18	33.03	20.1 - 43.2
Max Heart Rate	18	194.83	181.0 - 206.0
Vo_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$).	18	52.41	41.3 - 60.0

TABLE 3.5

SUBJECT NEUROMUSCULAR EVALUATION

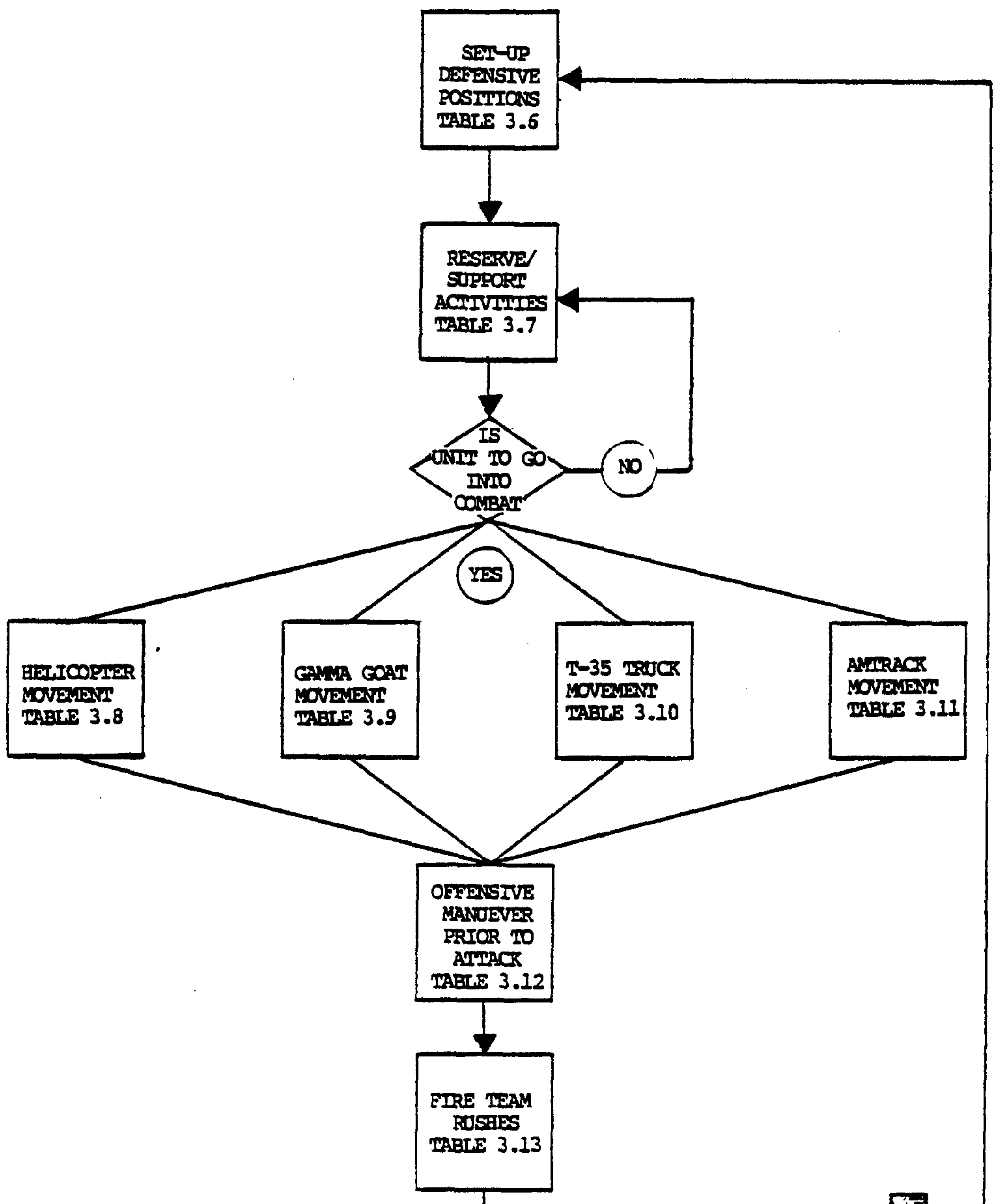
	N	X	Range
Standing Long Jump (cm)	18	239.48	204.8 - 264.0
Grip Strength, Right (kg)	18	52.81	42.5 - 73.5
Grip Strength, Left (kg)	18	50.78	41.0 - 68.0
Static Arm Pull Down (Kg)	16	122.88	95.0 - 155.0
Strength Index	16	216.69	169.0 - 376.0
Max Sit-Ups (2min.)	18	73.22	62.0 - 90.0

3.3 FIELD OBSERVATION DATA

Transcribed information obtained from the microcassettes was reduced to narrative form and transferred to a tally sheet by a single member of the observation team. Frequency counts were compared for each of the companies and examined for differences. Since no clear differentiation could be obtained between companies, the data were merged and compiled according to logical scenarios. Eight fundamental clusters of scenarios emerged from these narrative data. They are: (1). Set-up Defensive Positions; (2). Reserve/Support Activities; (3). Helicopter Movement; (4). Gamma Goat Movement; (5). T-35 Truck Movement; (6). Amtrack Movement; (7). Offensive Maneuver Prior to Attack and (8). Fire Team Rushes.

Each of these scenarios is displayed in table form and in flow chart form in Figure 3.1. Due to the small number of frequency counts available, it was felt that the data should be expressed as ranges, instead of mean values. However, it should be remembered that when an observed event was occuring the entire company was usually taking part in the same event (see Figures 3.3 - 3.6). Each of the identifiable scenarios is described in Tables 3.6 through 3.13. Included in these tables are descriptive data necessary to recreate the physical tasks, including posture, loads carried, terrain encountered, as well as geographical factors are noted. Temperatures encountered over the three- day period are displayed with the data, and also in Table 3.14. Simple dry bulb temperatures are displayed as a function of time in Figure 3.2.

Figure 3.1



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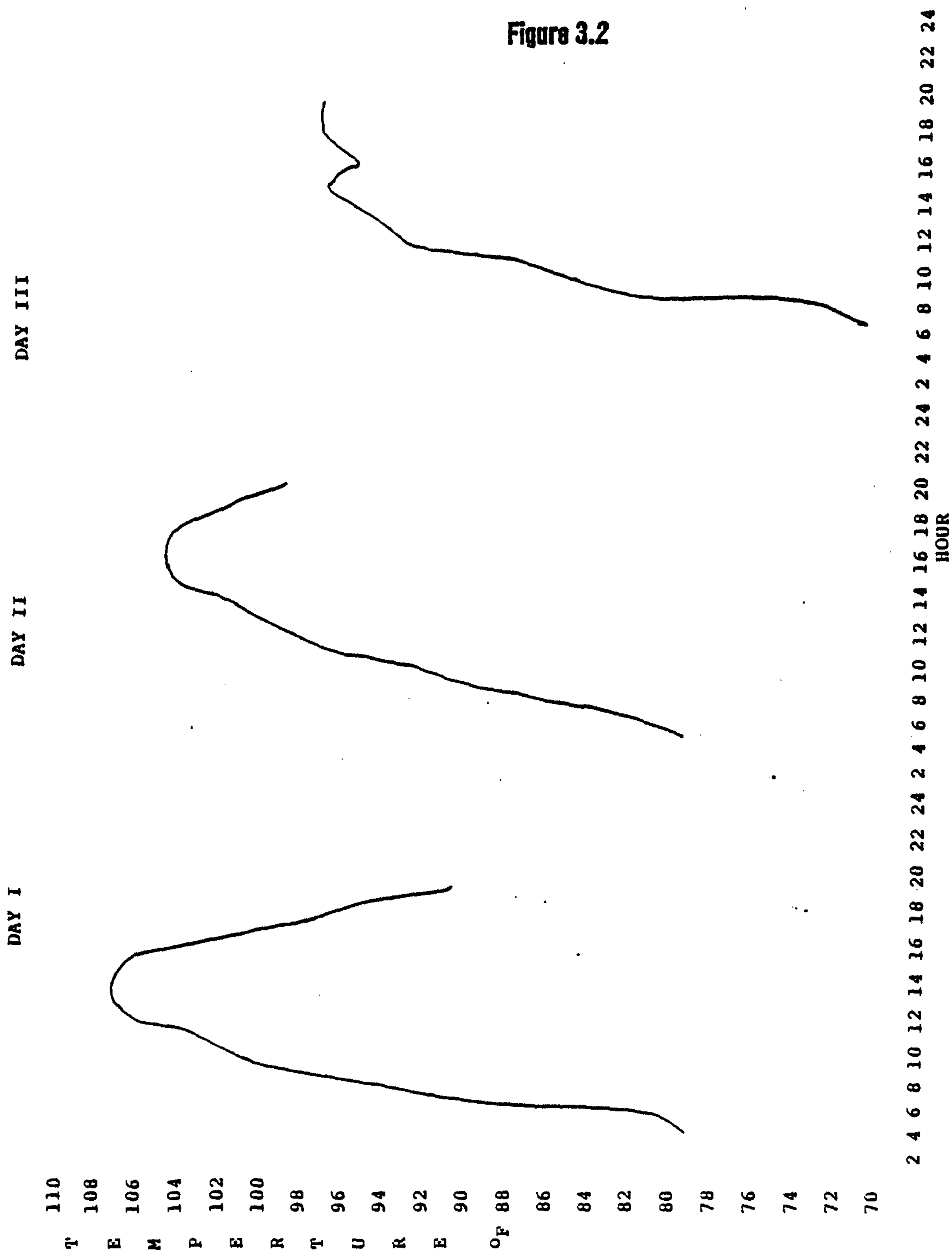

DAY I
DAY II
DAY III
TEMPERATURE °F
110 108 106 104 102 100 98 96 94 92 90 88 86 84 82 80 78 76 74 72 70
2 4 6 8 10 12 14 16 18 20 22 24 2 4 6 8 10 12 14 16 18 20 22 24 2 4 6 8 10 12 14 16 18 20 22 24
HOUR

Figure 3.2

TABLE 3.6
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING SET-UP OF DEFENSIVE POSITIONS

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Walking: Slow Walk -	Vertical	At least	.2 to	None	Heat: 93°F to	Variable	Non-hostile
2-3 mph from -		once per	2 hours		107°F.	terrain from	
vehicles to location		day			Loads: carried all	0°-60°	
of defensive position					equipment 20-50Kg.	encountered.	
Prepare Defensive							
Position:		Same		None		Surface varied from	
1. Dig with E-tool	Bent					sandy to rock.	
2. Carry rocks	Bent						
3. Stack rocks	Bent					Weight of rocks	
4. Scavanger sticks,	Vertical					varied from 2 to	
boards, etc.						30 Kg.	
5. Carry Supplies	Vertical						
C-rations	Veritcal						
Motor Rounds	Vertical						
M-60 Ammo	Vertical						
M-16 Ammo	Vertical						
Rockets	Vertical						
Laws	Vertical						
Water Cans	Vertical						
Sleep			2-6 hours	None	Evening Temperature		
Stand Watch			1 hour	None	90°F - 72°F		
Clean Weapon			less than 1 hour	None	102°F - 90°F		
Eat			1-1.5 hour	None	Same		

TABLE 3.7
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING RESERVE/SUPPORT ACTIVITIES

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Sitting:							
1. Trucks	Seated	1-2per day	30min. to	Exhaust fumes	Heat: $90^{o}F$ to $107^{o}F$		Non-hostile
	on packs.		5 hours.	tear gas.	usually without		
					shelter. Grip strength		
					required to keep		
					balance.		
2. C-7	Seated on	1-2per day	30min. to	Exhaust fumes	Heat: Inside C-7		Non-hostile
	packs		6 hours	tear gas, dust.	exceeded the outside		
					temperature by $10\text{-}25^{o}F$.		
3. In defensive		One day	2 to 10	None	Heat: $90^{o}F$ to $107^{o}F$,		Non-hostile
position		for 2 of	hours		no shade and occasion-		
a. Eat	Seated Prone	the 3 com-			ally inadequate water.		
b. Rest	Supine	paines					
c. Carry water	Upright						
cans							

TABLE 3.8
PROFILE OF PHYSICAL TASKS AND ENVIORNMENTAL FACTORS
DURING HELICOPTER MOVEMENT

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Loading Equipment and		1-2per day	2-10 min.	Dust, exhaust	Heat: 79°F to 95°F,	Terrain: Level	Non-hostile
Personnel				fumes	noise all operations		
1. Standing	Upright				done carring full		
2. Run onto helicopter	Upright				packs.		
3. Obtain seat	Seated						
4. Secure for lift off	Seated						
5. Riding	Seated		20-35 min.				
Unloading Equipment and							Non-hostile and
Personnel							Hostile
1. Run off of helicopter	Upright						
2. Set-up defensive							
position	Upright						

TABLE 3.9
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING GAMMA GOAT MOVEMENT

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Loading Equipment and		1-2 per day					Non-hostile
Personnel:							
1. Load packs on side	Upright	1 per event					
of vehicle (about 4')							
2. Step up into trailer	Upright	1 per event					
3. Secure seat	Seated	1 per event					
4. Brace for ride	Seated	1 per event					
5. Riding	Seated	1 per event	30min. to	Diesel exhaust,	Noise	Rough terrain	
			1 hour	extreme dust.			
Unloading Equipment and							
Personnel							
1. Jump off of vehicle	Upright						Non-hostile
2. Unload packs	Upright						

TABLE 3.10
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS DURING T-35 TRUCK MOVEMENT

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Load Equipment and		1-2per day	10-20 min.	Exhaust fumes,	Heat; 79^{0}F to 107^{0}	Leyle	Non-hostile
Personnel:				dust.			
1. Climb up onto truck -	Upright	1 per event					
without pack using							
steps on tailgate, or							
stepping on tires.							
2. Hand-up packs onto	Upright	1 per event					
truck.							
3. Stow packs	Bent over	1 per event					
4. Other climb up onto	Upright	1 per event					
truck.							
5. Secure seat on bench	Seated	1 per event					
or sit on packs.							
6. Brace for riding	Seated	1 per event	20-min. to	Exhaust fumes, dust	Heat: 79^{0}F to 107^{0}F.		Non-hostile
conditions			5 hours	on one occasion	noise		
7. Riding				tear gas.			
Off-load vehicle							
1. Jump off of truck	Upright	1 per event					
at tailgate.							
2. Hand-down packs	Upright	1 per event	2-3 min.				

TABLE 3.11
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING AMTRACK MOVEMENT

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Load Equipment and Personnel	Upright	1-3 per day 1 per event	10-20min.	Exhaust fumes dust.	Heat: 79°F - 107°F	Surface: Sand, rock, loose rock.	Non-hostile
1. Climb on to top of vehicle using hand holds, or use rear ramp if open.							
2. Pass-up pack and equipment	Upright	1 per event					
3. Stow/Lash Equipment	Bent over	1 per event					
4. Other enter vehicle; walk up ramp. 4' long at 10% grade, or enter rear door	Upright	1 per event					
5. Brace for riding condition	Seated	1 per event					
6. Riding	Seated	1 per event	30min. to 6 hours.	Exhaust fumes, dust.	Heat: Temperatures in excess of 120°F inside vehicle, noise.		
Unload:							
1. Use rear ramp, or climb down from top of vehicle.		1 per event				Usually level	If hostile pack may not be removed.
2. Hand down packs		1 per event					If non-hostile.

TABLE 3.12
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS DURING OFFENSIVE/MANEUVER PRIOR TO ATTACK

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Stage Equipment:	Upright	1 per day	10-30min.	Exhaust	Heat: 79^{o}F to 95^{o}F. Lifting ammo.	Surface: Sand rock, loose pack.	Non-hostile
Slow Walk- Slow Run into position:	Upright	one to five	10 min. to 1.5 hr.		Heat: 81^{o}F - 95^{o}F.	Same	Hostile
Lay down base of fire	Prone	one to five	2-5 min.	Gun powder, smoke, exhaust fumes from tanks.	Heat: 90^{o}F - 107^{o}F.	Rock, loose stone.	Hostile

TABLE 3.13
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS DURING FIRE TEAM RUSH

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Walking: Brisk Walk at 2.5 to 4mph. to the objective.	Veritcal either upright or bent at the waist.	One per rush	5-20 minutes	Smoke Grenades Gun Powder	Temperature: 84°F - 103°F. Equipment included weapon 6 ammo chips, 782 gear, helmet and liner body armor.	Terrained varied from level to 40° inclination. Surfaces were loose rock and solid rock. Many obsticles (large rocks, gullies), were encountered. Movements was both up and down hills.	Same
Walking: Slow Walk .5 to 2 mph. to manuever into final position to initiate rush.	Crouched	1-2 per rush	1-5 minutes (inter-mittent movement).	Same	Same	Same	

TABLE 3.13 (continued)
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING FIRE TEAM RUSH-(continued)

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Running: at sprinting pace for 10-20 meters per rush.	Vertical (either upright or bent the waist).	3-5 rushes per attack sequence.	2-5 seconds per rush. 5-12 min.	Same	All rushes undertaken were between the hours of 30 to 1130 hours: Temperature range $84^{o}F-103^{o}F$.	Terrain varied from 0^{o} to 40^{o} inclination surfaces varied from sandy in some of the level areas, loose rock, and rock on the hills sides.	Hostile under enemy fire.
Fire Weapon:	Either vertical, prone, or crouch depending on cover.	3-5 per attack sequence. Firing several rounds per rush.	10-20 seconds	Same	Same	Same	Same
Low Crawl:	Prone	Infrequent due to the rocky terrain and rough surface vegetation.	2-10 seconds	Same	Same	Same	Same

TABLE 3.13 (continued)
PROFILE OF PHYSICAL TASKS AND ENVIRONMENTAL FACTORS
DURING FIRE TEAM RUSH -(continued)

Essential Tasks	Posture	Frequency	Duration	Exposure To Chemical Agents	Exposure To Physical Factors	Geographical Factors	Combat Environment
Secure objective: overrun the objective and secure. This is usually followed by a rest period.	Vertical for the final rush; prone for rest period.	1 per attack sequence.	Rest period 10 to 30 minutes until remainder of the platoon arrives.	Same	Same	Usually the top of a hill, loose rock or solid rock.	Same

TABLE 3.14

TIME	TEMPERATURE (°F)	WET BULB TEMPERATURE	TEMP. DELTA
DAY ONE			
0500	79	49	30
0600	80	44	36
0700	84	44	40
0800	90	61	29
0900	95	69	26
1000	100	78	22
1100	102	73	29
1200	103	71	32
1300	105	76	29
1400	106	73	33
1500	107	81	26
1600	107	81	26
1700	106	79	27
1800	102	73	29
1900	96	63	33
2000	94	62	32
2100	90	56	34
.			
.			
DAY TWO			
0600	79	45	34
0700	81	40	41
0800	83	44	39
0900	90	53	37
1000	92	54	38
1100	96	59	37
1200	98	64	34
1300	100	64	36
1400	104	70	34
1500	104	74	30
1600	104	74	30
1700	102	73	29
1800	100	68	32
1900	97	68	29
.			
.			
DAY THREE			
0700	72	46	26
0800	74	52	22
0900	84	62	22
1000	88	65	23
1100	93	68	25
1200	95	69	26
1300	97	70	27
1400	96	66	30
1500	98	72	26
1600	98	68	30

Where appropriate, comments on exposure to environmental factors are noted. While no objective data were gathered on noxious fumes and levels of noise pollution, the magnitude of these stressors was great enough to warrant mention.

While the external loads carried in the ALICE pack ranged from a low of 5.44Kg to a high of 36.74Kg, there was little need for the marines to carry their equipment for sustained periods. (Data on typical loads and load/body weight relationships are shown in Tables 3.15 and 3.16).

TABLE 3.15

BODY WEIGHT EQUIPMENT RELATIONSHIPS

SUBJECT	TOTAL BODY WT.(KG)	EQUIPMENT WT.(KG)	EW/BW WT. (%)
KP	86.2	33.75	39.15%
JB	72.8	34.15	47.68%
BM	69.1	46.75	67.66%
RR	82.9	27.25	32.87%
PH	81.2	30.50	37.56%
GD	93.0	30.50	33.89%
PK	70.3	33.90	48.22%
DM	77.3	32.05	41.50%
TS	59.6	29.65	49.70%
RD	73.0	31.60	43.29%
RR	92.0	30.40	33.04%

TABLE 3.16

WEIGHTS OF VARIOUS EQUIPMENT CARRIED BY MARINES

EQUIPMENT ITEM	RANGE OF REPORTED WEIGHTS (KG)		
M-16	3.5		3.75
Helmet with Liner	1.75		
Body Armor	5.5	-	5.75
Web Belt with Ammo Pouches and two Full Canteens	4.75	-	6.5
Gas Mask	1.25	-	1.75
Alice Pack w/frame E-tool, Poncho, Rubber Pad, Ammo and other misc. items	5.25	-	17.5
Full Desert Water Bag	2.5		
Boots	1.5		
Fatigues & Cover	1.5		
M-203 Rifle w/Grenade Launcher	4.5		
Bandolier of M-60 Ammo	3.5		

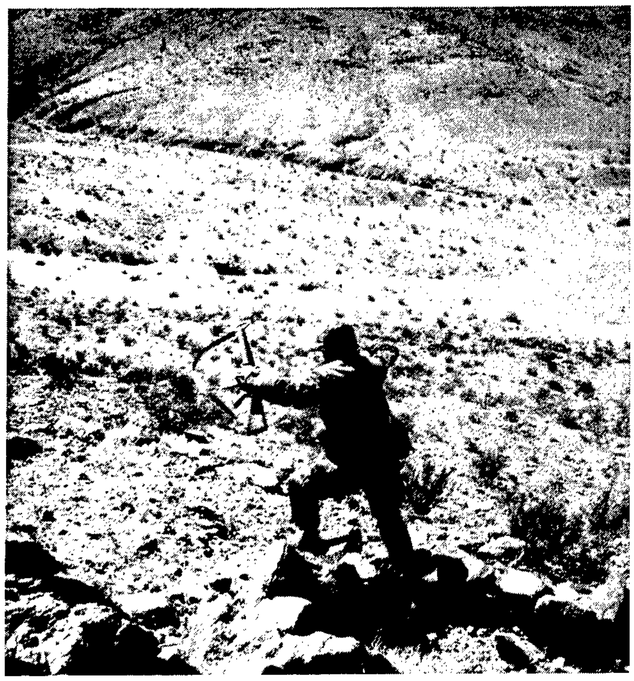
Transportation of troops by helicopter imposed high workload levels because the troops had to move quickly for distances up to 300 meters with full gear in order to board a helicopter. A similar workload requirement was imposed while exiting the helicopter because the landing zone was considered "hot" and, as such, movement away from the helicopter to distances up to 100 meters had to be accomplished with dispatch.

Estimates of the physical performance requirements (made by members of the observation team) are shown for each of the physical tasks/scenarios in Table 4.1. Estimates, using the data of Passmore and Durnin, and others

Defensive position construction
fig. 3.3

Marine taking military objective
fig. 3.4

Example of desert terrain
fig. 3.5



Fire team rush
fig. 3.6

were used to estimate energy costs of these tasks in kcal/min. These data and relevant discussions are contained in the final section of this report. Actograph records and Holter Monitor data were evaluated and found to add little to the observations. Heart rates in this environment are no doubt contaminated by the influence of heat; however, in those episodes where marines were monitored while wearing a Holter monitor and performing physical tasks, it may be inferred that the work would be classified as "heavy" [15], approaching 160 beats per minute , or 450 kcal/hour.

SECTION 4.0: DISCUSSION

The purpose of this investigation was to gather information regarding the physical performance tasks required of U.S. Marines operating in a desert combat environment. Data from nine separate observers were compiled according to the most critical and frequent physical tasks observed under these conditions. Several dimensions or components of physical fitness were identified as essential to the effective completion of a number of combat tasks. Specifically, a high absolute and relative anaerobic and aerobic work capacity has been identified as a necessary requirement. (Absolute work refers to energy being expended to move objects external to the body, while relative work refers to movement of one's own body.) Additionally, relative and absolute muscular endurance is a requirement for a significant number of the movement tasks that are performed while wearing load bearing equipment. The specific nature of the physical tasks will be discussed under the appropriate headings. Table 4.1 lists these critical and frequent physical tasks and provides estimates of the oxygen uptake costs associated with performance of the task. These estimates have been derived from the published references noted on the right side of the table.

4.1 Critical Tasks

For the purpose of this work, a critical task is one defined as extremely important to the successful completion of a job or task. An inability to complete such a task could conceivably result in loss or distruction of property, injury to self or co-workers, or loss of life. In essence, a critical task is significant to successful fulfillment of the MOS 0311 function.

4.1.1 Fire Team Rushes

The fire team rush was the most critical physical task observed at the CACC. This task required that members of a fire team to assault an enemy position while running upgrade and intermittantly fire a weapon. This activity is associated with high levels of energy expenditure. The total elapsed time for successful completion of this task (i.e., capturing of a individual hill or bunker) did not exceed 12 minutes per episode. In an actual combat situation, it is possible that these events could become linked together in a continuous sequence of rushes, thereby placing a large energy requirement on each marine.

The typical fire team rush (e.g., providing cover fire and intermittent sprints up a 30^{o} grade) involves both anaerobic and aerobic power. While most of these episodes were performed without ALICE packs, a substantial amount of equipment nevertheless was worn ("782" gear, body armor, weapon, ammo; see Table 3.16). Muscular power of the legs is therefore an important component of the rush. For short duration sprints typical of a single episode, superior aerobic conditioning does not provide any advantage in performing tasks of this type [16]. However, in those scenarios in which several of these episodes of charging and firing a weapon are linked together, the aerobic requirement would be dramatically increased. Under those conditions in which a rush lasted longer than one minute, aerobic energy may be needed to supply 30-40% of the total energy requirement [17], and those cases of sustained performance exceeding 6 minutes aerobic energy would supply nearly 100% of the requirments.

Few casualties were observed during the CAX, but those that were observed were the victims of the combination of heat and the physical stress of fire team rushes. It is postulated that the overall intensity of these activities (and therefore the resultant casualties) may be increased significantly during real combat (as was the case in the Eqyptian-Israeli war of 1973 [18]). Heat will be discussed in greater detail in Section 4.3.1 below.

4.1.2 Movement by Helicopter

The marines were seldom required to run or attempt to run while wearing and carrying all the equipment listed in Table 3.15. The exception to this general observation occured during boarding and off-loading of helicopters. Since helicopters frequently land at some distance from the staging area and because a minimal amount of time should be spent on the ground to avoid enemy detection and fire power, expediting the movement of a platoon onto the helicopter is both necessary and physically stressful. The failure of any one marine to move rapidly and to successfully board the helicopter could compromise the entire operation. In off-loading, movement away from the helicopter to establish a defensive position is also an urgent matter, since it is assumed that the platoon would be receiving fire. This task represents the single highest level of anaerobic power required of all the observed combat tasks. Recovery from the boarding episode would be expected to occur in-flight, while the off-loading process could place the unit in sustained combat without an opportunity for physical recovery. In this case, the buffering effects of enhanced physical conditioning (i.e., increased tolerance to high levels of repeated anaerobic activity) would be advantageous.

4.2 Frequently Performed Tasks

The next most critical category of tasks were found to be necessary for the effective completion of support and reserve activities. While high energy requirements are not associated with these tasks, they are nevertheless important to the overall mission of the marines in a desert environment. These tasks are described below.

4.2.1 Climb, Load, Lift and Carry

In a combat theater centered around the use of mechanized and motorized transportion, the individual marine is still required to manually handle supplies and equipment. Typical of each day's operation is the loading of one's personal equipment (ALICE pack) and one's self onto the various modes of transport. Sufficient upper torso strength is a necessary requirement to effectively accomplish this task. This requirement is most evident while loading into T-35 trucks and stowing gear on the Amtracks. We were able to weigh nearly all of the regular issue equipment and found the maximum weight to be about 40 pounds. Packs were the most frequently loaded object, followed by C-ration cases and 5-gallon water cans (45 pounds). Rocks were frequently carried in order to build defensive positions (described in greater detail below). We were unable to measure the weight of these rocks due to the limitations of our portable scales. However, estimates of their weight ranged from 25-50 pounds each. Because carrying objects by hand is far less efficient than carrying objects on the back [19,20], we did not observe many marines carrying objects (such as water cans) by hand more than 70 meters. Walking with loads will be discussed in Section 4.2.3.

4.2.2 Digging

The use of an E (entrenching) tool is the primary means of constructing fighting holes or defensive positions. While the physical costs of digging with more traditional methods of excavation have been determined [21], two major differences under the present conditions should be noted. First, the short shaft on the shovel required that digging be conducted while squatting. Secondly, if the marine was receiving fire, the rate of digging was significantly accelerated. Rocks were often used to supplement the construction of the defensive positions because the ground was frequently too rocky to dig. Since rocks were readily available, they were the primary material used in building personal fighting holes.

4.2.3 Walking/Marching

Episodes requiring sustained marching were not observed. Only one company was required to walk approximately one mile to reach a staging area. In most of the scenarios in which walking was required, frequent rest stops occurred, allowing for stragglers to rejoin the unit. It should be noted, however, that stragglers were rarely afforded any periods of rest. It is conceivable that any requirement to walk long distances on foot in this environment could readily turn the situation into a contest for survival. Many investigators have determined the energy costs of sustained hiking/marching in a number of environments. The most relevant of these citations are shown on Table 4.1.

4.3 Environmental Overlays

Mechanized/motorized desert combat is distinctly unique in the demands placed upon men and machine. Failure to recognize the external load-bearing conditions and environmental constraints in assaying the physical demands of performance in a desert environment could distort the estimates of physical requirements under these conditions.

4.3.1 Heat

The most important factor impacting on sustained combat is the intense heat that potentiates the stress of physical work. Time to complete tasks and distances covered were significantly altered by temperature. While the literature is mixed regarding the effects of heat upon energy costs during various physical activities, it is apparent that in the untrained individual, heat does increase the cost of performing physical work [22]. Consolazio has documented the increased energy requirement for performance in extremely hot climates [23]. Goldman has cautioned that the containment of heat caused by wearing CBR protective equipment even in a temperate environment may have negative consequences [24]. In a similar vein, he warns against ardous work in hot environments. It has also been demonstrated that increased levels of aerobic fitness significantly improve tolerance to physical work in hot environments [25]. Acclimatization to hot environments has been shown to take about two weeks [26].

4.3.2 Water

Water represents a logistical weapon in the desert. Without it, movement must be curtailed or stopped. If water is withheld for an extensive period of time disaster can befall the combat unit. In man, the loss of 2 quarts of body water results in a 25% reduction in efficiency [27]. It is estimated that approximately five gallons of water per day are required for each individual for all purposes in this climate in order to maintain normal physical efficiency [28].

4.4 Deriving Physical Fitness Standards

A considerable amount of research has investigated the relationships between energy costs and the carrying or wearing of equipment [29-36].

These studies suggest that pace will adjust to the load being carried. Estimates of the energy costs associated with many of these Marine Corps desert tasks can be inferred through work performed in the same or similar types of occupations. Environmental conditions associated with the performance of these tasks; however, markedly change energy costs. It is recommended that a standardized set of physical tasks derived from critical episodes identified above be empirically measured under conditions similar to those observed during these desert operations.

Studies can be performed in a field setting as suggested by Liddell (37), Consolazio (38) or Verma and others (39) through the use of portable metabolic measurement equipment. The face validity of this approach is offset against the inconvenience associated with working outside of the laboratory environment. As a substitute procedure, simulation of these scenarios in the laboratory can be accomplished in the following manner: an environmental chamber can be used to accurately replicate temperatures and humidity encountered in the desert environment. A research treadmill will allow for programming and reproduction of grades and speeds required during the critical tasks. Using the observed tasks as the criterion of performance, a standardized set of reproducible, laboratory-based tasks can be conducted during which metabolic measurements would be assessed. Due to the nature of the combat environment and the time constraints imposed upon the completion of these tasks, a number of specific tasks should be performed in a sequential manner in order to fully tax the subject's oxygen delivery system.

A battery of simple and complex physical fitness tests would also be administered to the same subject group in a different time setting. The criteria for inclusion of an item in the battery of predictors should be as follows: (1) be a "pure" (one dimension) predictor; (2) have a high degree of test-retest reliability; and (3) lend itself for use as an expedient, easily administrated performance test.

Multiple regression analysis of the relationships between the battery of predictors and the criterion tasks would insure that the Marine Corps had a truly useful, job-related physical performance test that would accurately predict combat readiness for a desert environment. This methodology would give the appropriate weightings for each of the dimensions of fitness in accordance with the order of their importance in predicting performance on the criterion tasks. It would also allow for the intelligent establishment of minimum levels or cut-off, idenytfying those individuals whose physical abilities, being only marginal, could compromise the successful completion of a combat operation.

No doubt, the best approach to the development and validation of a comprehensive job-related test is to ensure that data from all theaters of operation are assessed and included in the taxonomy of job tasks. This will be accomplished in future work under this program. Contingency planning for combat preparedness should always include the worst case condition as the criterion of performance effectiveness.

4.5 Summary

In the desert environment, the most critical task in terms of cardiovascular fitness (i.e. stamina) is the fire team rush. It is estimated that the typical, single episode in a fire team rush scenario required an oxygen uptake in excess of 45 $ml \cdot kg \cdot min^{-1}$, with peak demand exceeding 50 $ml \cdot kg \cdot min^{-1}$. A requirement for upper torso strength is evident in the loading of equipment and one's self onto the various modes of transportation. While this task is usually accomplished without the

ALICE pack, nevertheless, a significant amount of mass beyond body weight is worn during the performance of this task. Estimates of the forces necessary to accomplish this task range from 120-160 pounds in the shoulder girdle and elbow flexor groups. Clear demonstration of leg strength was not evident in any of the observed combat scenarios.

The exact physiological requirements for these critical tasks should be discovered under simulated laboratory conditions. Comensurate with this approach, candidate predictor tests could be developed that would correlate highly with these laboratory based tasks.

TABLE 4.1

SUMMARY OF OBSERVED PHYSICAL TASKS WITH REFERENCE TO ENERGY COSTS*

CATEGORY/TASK	KCAL·MIN^{-1}	CITATION
Sitting in vehicle	1.7	21
Standing (no load)	1.51	21
Standing, loaded		
10kg	1.56	34
20kg	1.78	34
30kg	2.07	34
WALKING:		
slow (no load) 5.5 Km/hr smooth surface (91.6 m/m)	5.6	21,34 36
rough surface " "	7.6	
sandy surface, (50 lbs)	9.87	43
loaded, up grade (40 Kg, +10%)	9.91	35
loaded, down grade (40 kg, -10%)	4.66	32
mechanical energy aspects of running and walking	- -	46,47,48
RUNNING (5-7 mph)	1.5 kcal/kg/mile	21,42,45
low crawl	9.1	21
impact of body weight on energy cost	o.o47(w) + 1.024	49
Implications for sustained performance		50,51,52
digging	5.4	21
lifting/loading	4.5-10.0	53,54, 55,56

*Assuming 150 lb. individual for most values

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