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REPORT NO. T 4/87

ASSESSMENT OF PHYSICAL ACTIVITY INTENSITY DURING INFANTRY COMBAT-SIMULATED OPERATIONS

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

DECEMBER 1986

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Technical Report
No. T4/87

Assessment of Physical Activity Intensity during Infantry Combat-Simulated Operations

by

Robert P. Mello, Bruce H. Jones,
James A. Vogel and John F. Patton III

December 1986

US Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760-5007

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER T4/87 2. GOVT ACCESSION NO. AD-A180038	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Assessment of Physical Activity Intensity during Infantry Combat-Simulated Operations	5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert P. Mello, Bruce H. Jones, James A. Vogel and John F. Patton III	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Research Institute of Environmental Medicine Natick, MA 01760-5007	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Same as 9. above.	12. REPORT DATE December 1986 13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Infantry combat-simulated operations, Heart Rate Monitoring, Physical Intensity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to estimate the intensity of physical activity of infantrymen during a combat-simulated five day field operation by means of continuous heart rate (HR) recordings. Subjects were 29 soldiers forming 4 rifle squads. Each squad rotated daily through 4 separate terrain areas, each with its own combat-simulated scenario, performing the same scenario on the first and last day. Sleep was limited to one 5 hour period per night. Physical activity was estimated by taping HR with Oxford Medilog cassette recorders with an electrocardiographic (ECG) channel. Mean daily average HR (excluding sleep and

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) resupply time) decreased from a high of 101 beats per min (bpm) on day one to a low of 89 bpm on day five. This suggests the progressive development of physical fatigue, as the five day operation progressed. A 10 km forced march proved to be the single most demanding event resulting in a mean HR of 128 bpm for 140 minutes. Other periods of sustained high HR were associated with moving to and from mission objectives. Time at or above 50% of maximal HR averaged only 37 minutes per day while HR 75% was only 2.5 minutes, both times tending to decrease from day 1 to day 5. The results of this study suggest that: 1) continuous cassette HR recording is a suitable method of monitoring the intensity of physical activity during strenuous field operations, 2) sustained high physical activity is minimal in rifle squads in simulated combat, 3) this activity intensity can adequately be supported by an aerobic capacity (VO_2max) of 50 ml O_2 per kg per min., 4) the highest sustained HR was produced by marches or movements to contact, and 5) the sleep deprivation and physical fatigue of combat operations cause infantrymen to perform at a slower rate regardless of operational demands as the operation progresses.

Acknowledgement

The authors wish to express their appreciation to the following people whose contributions were invaluable to the successful completion of this study.

1. COL Fred R. Drews, Director, Army Physical Fitness Research Institute, Carlisle Barracks, PA who conceived and directed the overall project of a five day sustained infantry operation.

2. SP5 Frank Frederick who developed the computer program, and assisted in the design of the Datatape Analysis System.

3. Mr. Andrew Damokosh and SP4 Eric Bertrand who contributed in the organization and reduction of the data.

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ABSTRACT

The purpose of this study was to estimate the intensity of physical activity of infantrymen during a combat-simulated five day field operation by means of continuous heart rate (HR) recordings. Subjects were 29 soldiers forming 4 rifle squads. Each squad rotated daily through 4 separate terrain areas, each with its own combat-simulated scenario, performing the same scenario on the first and last day. Sleep was limited to one 5 hour period per night. Physical activity was estimated by taping HR with Oxford Medilog cassette recorders with an electrocardiographic (ECG) channel. Mean daily average HR (excluding sleep and resupply time) decreased from a high of 101 beats per min (bpm) on day one to a low of 89 bpm on day five. This suggests the progressive development of physical fatigue, as the five day operation progressed. A 10 km forced march proved to be the single most demanding event resulting in a mean HR of 128 bpm for 140 minutes. Other periods of sustained high HR were associated with moving to and from mission objectives. Time at or above 50% of maximal HR averaged only 37 minutes per day while HR 75% was only 2.5 minutes, both times tending to decrease from day 1 to day 5. The results of this study suggest that: 1) continuous cassette HR recording is a suitable method of monitoring the intensity of physical activity during strenuous field operations, 2) sustained high physical activity is minimal in rifle squads in simulated combat, 3) this activity intensity can adequately be supported by an aerobic capacity ($\dot{V}O_2max$) of 50 ml O_2 per kg per min., 4) the highest sustained HR was produced by marches or movements to contact, and 5) the sleep deprivation and physical fatigue of combat operations cause infantrymen to perform at a slower rate regardless of operational demands as the operation progresses.

INTRODUCTION

The rigorous demands of continuous combat operations tax both the physical and mental capacities of soldiers. The soldier in combat is required to perform a wide range of physical activities from short, quick bursts of energy to long, sustained marches over all manner of terrain. In order to establish the fitness requirements necessary to succeed under such conditions, it is essential to know the nature of the physical demands required for successful combat performance.

Because of the difficulties involved in the direct measurement of energy expenditure by oxygen consumption ($\dot{V}O_2$), we chose to measure continuous heartrate (HR) as an indicator of energy cost. When exercise can be carefully controlled, such as on a treadmill or bicycle ergometer, $\dot{V}O_2$ and HR are closely related and the relationship is linear over most of the range of measurement (10). It is common practice to establish a HR - $\dot{V}O_2$ calibration curve on a particular subject, and then use this curve to convert HR recorded in the field into $\dot{V}O_2$ values previously determined in the laboratory (2,3). Continuous HR recordings can then be used to examine such parameters as: the intensity of exercise, its overall pattern and duration, and the frequency and duration of rest/recovery periods. The main problem with estimating energy expenditure from HR-$\dot{V}O_2$ calibration curves is related to the fact that the average 24 hour HR value is low and it is at this range where errors in prediction can occur (10). The usual HR-$\dot{V}O_2$ calibration curve is most reliable for people performing a great deal of physical exercise during a specific 24 hour period. For most individuals, variation at the lower end of the HR-$\dot{V}O_2$ curve can result in substantial error in the prediction of 24 hour energy expenditure. This report made no direct attempt to calculate energy expenditure from 24 hour HR measurement. However, data from 24 hour HR recordings were used to estimate the pattern and degree of physical activity for the 29 soldiers throughout the entire course of the five day simulated combat scenario.

METHODS

Twenty-nine male soldiers comprising four intact rifle squads from the 2nd Battalion, 47th Infantry Regiment, 3rd Brigade, 9 Infantry Division at Fort Lewis, Washington, completed a five day combat-simulated scenario. The scenario required the squads to perform both offensive and defensive operations, using foot movement on a nearly continuous basis to simulate actual combat conditions.

During the week preceding the five day field exercise, aerobic power ($\dot{V}O_2max$) and maximal heart rate (HRmax) were determined using an interrupted treadmill running test patterned after the method of Mitchell et al (11). The procedure began by having each subject run at six mph and 0% grade for six minutes, followed by a five to ten minute rest period. Two to four additional runs were then performed, each three to four minutes in length and interrupted by rest periods. After the initial six mph run, a standard running speed based on each subject's HR response was determined, and all subsequent exercise intensities were increased by raising grade only. During the last minute of each run, expired air was collected in plastic Douglas bags and exercising HR was recorded on a Hewlett-Packard model 1511 electrocardiograph. A plateau, or decrease, in $\dot{V}O_2$ with an increase in intensity was defined as $\dot{V}O_2$ max. A plateau was defined as an increase of less than 2.0 ml O_2/kg of body weight per minute with a concurrent increase of 2.5% grade. Expired air volumes were measured with a Collins 120 liter chain-compensated spirometer. Oxygen and carbon dioxide fractions were determined with an App.ied Electrochemistry S-3A fuel cell and a Beckman LB-2 infrared analyzer, respectively.

Following baseline, pre-scenario measurements all subjects were given a day of rest prior to the commencement of the five day combat scenario. All squads began the scenario with a ten kilometer road march out to the appropriate test area. Each squad then rotated through one of four testing areas (quadrants) for each day of the five day field exercise (Table 1). On the fifth and last day of the scenario each squad repeated the activity schedule of the initial day. In each quadrant, squads were given a series of mission assignments to be completed at specific times during each twenty-four hour time period (Table 2). One five hour block of continuous sleep was allowed for each squad for each 24 hour period.

The physiological demands of the scenario were estimated on a minute by minute basis by the use of portable electrocardiographic cassette units (Oxford/Medilog 4-24) which recorded HR from all subjects during the course of the entire five day scenario. Three lead V_5 ECG tracings were obtained with American Hospital Supply Plia-Cell electrodes which were replaced as necessary each day. Cassette tapes were changed at 0600 each day and the functional integrity of each subject's tape recorder and ECG electrodes were evaluated at this time. Subject's daily HR's were recorded on 24 hour cassette tapes which were then replayed, for computer analysis, through an Oxford/Medilog ECG analysis system. System components consisted of the following:

a) An Oxford Instruments high speed replay unit (MDL PB-2) (replays cassette tapes 60x faster [24 hrs =24 min replay time])

b) An ECG signal conditioning amplifier (MDL PD-2)

c) A Pulse Interval Timer (MDL PIT-2(60))

d) A Hewlett-Packard Model 85A desktop computer

e) A Hewlett-Packard Model 5328B Universal Counter

f) A Tektronix Inc. Model 564 Storage Oscilloscope

g) A Tektronix Inc. Model 3A6 Dual Trace Amplifier

The tape analysis system operated in the following manner. Each datatape was replayed on the Oxford replay unit. Conditioning of the ECG signal was accomplished by the PD-2 ECG amplifier. Adjustment of the high and low frequency cutoffs and the gain magnitude while observing the signal trace quality on the Tektronix oscilloscope permitted optimal amplification of the R-wave and hence reliable R-R interval counts. Once the ECG signal was properly adjusted it was relayed to the pulse interval timer for trigger level adjustment in order to count each individual R-wave. From the Pulse Interval timer, the signal was then fed into an H/P Model 5328B Universal Counter, which was a "slave" to the HP 85A desktop computer, which in turn was programmed to record minute HR's for the entire 24 hour period.

The HP 85A program functioned in the following manner. It was primarily an averaging program printing a running average of successive, similar HR's rather than minute by minute rates. The program constantly compared each minute HR to the values of the previous two minutes' HR (Triplet comparison). If all three values remained within a 19 beat range of each other the running average was maintained. However, if a specific minute's count exceeded the 19 beat criterion then the current value (recent average in memory) along with the total number of minutes comprising that average was printed out. A new triplet comparison was then begun (last two minute by minute counts from previous average were held in memory) using the same 19 beat criterion. This cycle continued throughout the entire course of the datatape. This triplet comparison allowed the computer to identify and display abrupt changes in HR for minute to minute values while still permitting the averaging of similar HR's for ease of interpretation.

In addition to identifying immediate responses (± 19 beat difference in a three minute comparison) this program also identified the development of trends. A trend occurred when, for each four minute count, a consistent rise (or fall) of five or more bpm was observed through each successive minute e.g. nervous tension, mild exercise, or slow recovery HR. The entire four (or more) minutes' trend was then printed out and a new comparison begun. The program also displayed each minute's HR in a running graphic form (0 to 200 bpm) and printed the HR (bpm) for the interval with the symbol "*" to the left of each minute's numerical count. This program also printed "real-time" (in hours) in the right side column of every printout (Fig 1).

Finally, the program computed and printed the following values: total HR per 24 hour period, mean HR per 24 hour period, and for each hour; mean HR, minimum and maximal HR's, and total HR sum.

RESULTS AND DISCUSSION

The main focus of this study was the use of recorded HR to estimate the degree of physical activity of 29 infantrymen who participated in a 5-day, combat-simulated field exercise. No attempt was made to convert HR into kilocalories of energy expenditure for several reasons. First, the derivation of a simple regression relationship from such specialized activities as running on a treadmill or riding a cycle ergometer might not hold true for the variety of activities performed by our subjects during the 5-day scenario. Secondly, other complicating factors such as environmental temperature, emotion, food intake, fatigue, smoking, and the effect of previous exercise may also influence HR without a proportionate increase in energy expenditure.

The anthropometric and physiological data for the 29 test subjects who participated in this study are listed in Table 3. The overall fitness level of this group of subjects was excellent (mean $\dot{V}O_2max$= 53.8 ml/kg.min), and comparable to other infantry data (12). These data suggest that trained infantrymen appear to have no difficulty in completing a 5 day simulated combat field exercise. This was evidenced by the fact that the mean HR for all 4 squads for the 17 hours of activity for each day of the scenario was only 94 bpm which is equivalent to approximately 25% of the HR reserve.

Figure 2 depicts the mean heart rate response of the four squads to the 5-day scenario. The average daily heart rate responses for the entire scenario ranged from a high of 101 BPM on Day 1 to a low of 89 BPM on Day 5. It can be seen from this figure that Day 1 was the most physically demanding while Day 5 was the least stressful of the scenario. The activities of Day 1 were identical to those of Day 5 with one exception, a 10 kilometer road march which was performed by all squads at the outset of Day 1.

Table 4 summarizes the mean heart rate data of each squad for each day of the scenario. It is presented in the format of a 17 hour active period and a 5 hour sleep period. A 17 hour period of activity was chosen because it was the investigators' opinion that the hours immediately preceding and following the sleep period were transitional phases between activity and sleep or vice versa and hence were not valid data for either period. It can be seen from this table that the mean HR's for all four squads were strikingly similar when compared over the entire duration of the 5-day scenario (94 bpm for the 17 hour active period, 59 bpm for the 5 hour sleep period). Day 1 again stands out as the most demanding of the scenario. A comment is appropriate concerning the apparent lack of data for approximately half the subjects on Day 3. Weather conditions were excellent for the first two days of the scenario and datatapes were of good to excellent quality, hence the ECG electrodes on all subjects were not changed between Day 2 and Day 3. On the morning of Day 3, however, a heavy downpour occurred, and it rained intermittently for the remainder of the day and night. Large, cloth-type electrodes had been used and the integrity of the preparation was completely destroyed on approximately one half of 29 subjects for that day. It is now policy in our laboratory to change electrodes at least every other day and to use electrodes which are impervious to water.

The most demanding activity of the entire scenario was the 10K road march with a mean time of two hours and twenty minutes. The mean HR for the 29 subjects during the course of this march was 128 bpm. Using the findings of the 10K march as a barometer it can be seen (Figures 3 to 6) that in almost all instances the highest sustained HR's were achieved when the squads were marching (either "moving to" or "moving away from" a military objective). The effect of the 10 kilometer road march can be appreciated by contrasting the 17 hour active HR's of Day 1 with those of Day 5 since quadrant and mission assignments were identical for these days, with the exception of the road march. An examination of Figure 2 and Table 4 illustrates the point that the 12 bpm difference (101-89 bpm) between Day 1 and Day 5 was largely due to the two hour and twenty minute 10K road march accomplished at the onset of Day 1.

Figures 3 to 6 illustrate the mean hourly squad HR levels for each quadrant (testing area) on every day of the scenario. The major missions to be accomplished for each quadrant are written at the bottom of each graph with the approximate time of their execution. An observation that becomes immediately apparent is the tightness of fit of the individual mean squad HR's over the course of the entire day even though each squad accomplished the missions of each quadrant on different days of the scenario. A notable exception was Squad 4 in quadrant 4 on day 5 whose apparent reaction to sniper fire was to ignore the fire and find a place to recover for several hours (latter part of the last day of the scenario). In general, the most active part of the day was during the daylight hours while the periods of least activity were at night, with the possible exception of Day 1.

Table 5 presents the total time for each subject monitored in the study at which 50% of maximal active HR or above, was attained. HR50% is the net HR derived from subtracting each subject's resting HR from his treadmill maximal HR, multiplying by 0.5 and then re-adding the resting HR value. It is a useful indicator of the intensity of physical exertion (9) and serves to reduce the amount of variation that can occur among subjects thus correcting for such variables as resting metabolic rate, characteristic individual HR and state of training (7). A perusal of the values in Table 5 indicates that Day 1 was the most physically demanding of the field exercise for 3 of the 4 squads (HR50% = 67min). Also, the average HR50% value for all squads for the entire scenario was only thirty-seven minutes. This means that each subject during the course of the scenario achieved 50% of net maximal HR for only 37 min of each day.

Table 6 presents similar data to that of Table 5 but in this instance the computation is for the HR75% level. It is surpising to note the brief period atwhich HR75% was attained for all subjects on each day of the scenario. Again the highest recorded levels were observed on Day 1. The mean time spent on activity requiring greater than HR75% for all subjects over the five day period was only 2.4 min/day.

In conclusion, this five day combat-simulated scenario produced physical activity demands that were relatively moderate and well within the limits of the aerobic capacity of the subjects tested. It is likely that in sustained combat operations fitness capacities other than aerobic power may be more limiting and may more directly influence overall performance.

Conclusions

The results of this study suggest that:

(1) Continuous cassette HR recording is a suitable method of following physical intensity during strenuous field operations.

(2) Sustained high physical activity is minimal in rifle squads in simulated combat.

(3) This activity intensity can adequately be supported by an aerobic capacity ($\dot{V}O_2max$) of 50 mℓ O_2 per kg per min.

(4) The highest sustained HR was produced by marches or movements to contact.

(5) The sleep deprivation and physical fatigue of strenuous field operations may cause infantrymen to perform at a slower rate as the exercise progresses.

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TABLE 1: Scenario quadrant schedule

Quadrant	Day 1	2	3	4	5
1	S-1	S-4	S-3	S-2	S-1
2	S-2	S-1	S-4	S-3	S-2
3	S-3	S-2	S-1	S-4	S-3
4	S-4	S-3	S-2	S-1	S-4

Table 2. Mission schedule of scenario

QUADRANT	MISSION	TIME
1	RAID	0600
	ROADBLOCK AND VEHICULAR AMBUSH	1300
	POINT RECONNAISSANCE/RAID	1700
	ESTABLISH PATROL BASE	2300
	STAND DOWN	0100
	STAND TO AND MOVE TO RESUPPLY POINT	0500
2	AREA RECONNAISSANCE/AMBUSH	0600
	DEFEND EASTMAN AND FOLSOM HILLS	1600
	STAND DOWN	0100
	STAND TO AND MOVE TO RESUPPLY POINT	0500
3	SECURE SITE AND RESUPPLY	0600
	MOVEMENT TO CONTACT	0630
	VEHICULAR AMBUSH	1100
	AREA RECONNAISSANCE/ATTACK AND DEFEND	1400
	ESTABLISH PATROL BASE	2230
	STAND DOWN	0100
	STAND TO AND MOVE TO PARTISAN LINK-UP	0500
4	PARTISAN LINK-UP AND RESUPPLY	0600
	RAID/RESCUE & EVACUATE WOUNDED/PARTISAN	0600
	SECURE AND HOLD LANDING STRIP/DEFEND	1600
	STAND DOWN	0100
	STAND TO AND MOVE TO RESUPPLY POINT	0500

Table 3. Physical characteristics of subjects (Mean ± SD).

	Squad 1	Squad 2	Squad 3	Squad 4	Total
N	7	8	7	7	29
Age (Yrs)	23.1 ± 4	23.1 ± 3	21.4 ± 2	21.0 ± 2	22.2 ± 3
Ht(cm)	173.9 ± 7	174.6 ± 4	172.4 ± 8	173.7 ±10	173.9 ± 8
Wt(kg)	78.3 ± 9	73.1 ±11	72.9 ±13	76.3 ± 9	75.1 ±10
% BF	14.8 ± 5	14.0 ± 6	17.1 ± 5	17.0 ± 5	15.7 ± 5
$\dot{V}O_2max$ (ml/kg/min)	52.8 ± 5	54.6 ± 6	55.8 ± 6	51.9 ± 6	53.8 ± 6
HR_{max}	193 ± 7	192 ± 10	194 ± 8	194 ± 10	193 ± 9

Table 4. Mean heart rates during the 17-hour active and 5-hour sleep periods (mean ± SE; n = number of subjects).

Squad		Day 1	2	3	4	5	Total
1	Active	102±3	90±6	90±7	95±5	92±3	95±3
	Sleep	63±3	59±4	60±5	60±2	59±2	60±2
	n	5	3	2	6	6	5
2	Active	98±4	97±5	88±4	95±3	87±4	94±3
	Sleep	60±2	60±3	63±3	55±3	60±4	59±3
	n	8	8	6	6	5	5
3	Active	99±4	99±9	102±5	85±2	90±2	93±4
	Sleep	57±4	57±2	63±4	53±1	56±2	58±2
	n	5	3	3	5	4	5
4	Active	103±6	90±3	88±7	96±3	85±5	93±4
	Sleep	61±4	60±3	58±6	57±2	57±5	59±4
	n	6	7	4	6	5	5
Mean	Active	101±1	94±2	92±3	93±3	89±2	94±1
	Sleep	60±1	59±1	61±1	56±1	58±1	59±1

Table 5. Minutes per day at or above heart rate 50%.

Squad	Mean HR 50%	Day 1	Day 2	Day 3	Day 4	Day 5
1 (N=5)	128	83	50	12	67	33
2 (N=8)	133	81	72	24	35	36
3 (N=4)	140	21	28	46	12	10
4 (N=7)	138	83	14	21	23	17
Mean=24)	135	67*	41	26	34	24

HR 50% = (HRmax - HRrest) X 0.5 + HRrest

*10 km Road March Performed on Day 1.

Table 6. Minutes per day at or above heart rate 75%.

Squad	Mean HR 75%	Day 1	2	3	4	5
1 (n=5)	161	1.6	2.0	1.5	2.0	0.6
2 (n=8)	162	6.4	3.0	0.7	2.0	3.6
3 (n=4)	165	3.7	9.0	7.0	0.5	1.0
4 (n=7)	167	2.0	0.0	3.0	0.0	0.4
Mean(n=24)	164	3.4	3.5	3.1	1.1	1.4

HR 75% = (HRmax - HRrest) X 0.75 + HRrest

```
SUBJECT NUMBER   9401
DATE    830722

TOTAL COUNTS-24 HRS= 83395
BPM-24 HRS= 57.913

      STARTING TIME    6: 0

TIME 7          RECORD 0
    MIN= 71         MAX 116
  SUM= 5433     AVG BPM= 90 55

TIME 8         RECORD= 0
    MIN= 78        MAX= 132
  SUM= 6732     AVG BPM= 112.2

TIME 9         RECORD= 0
    MIN= 110       MAX= 144
  SUM= 7234     AVG BPM= 120 57

TIME 10         RECORD= 0
    MIN= 96        MAX= 126
  SUM= 6222     AVG BPM= 103.7

TIME 11         RECORD= 0
    MIN= 89        MAX= 170
  SUM= 7105     AVG BPM= 118 42

TIME 12         RECORD= 0
    MIN= 89        MAX= 135
  SUM= 6707     AVG BPM= 111.78

TIME 13         RECORD= 0
    MIN= 92        MAX= 147
  SUM= 6639     AVG BPM= 110 65

TIME 14         RECORD= 0
    MIN= 74        MAX= 155
  SUM= 5299     AVG BPM= 88 317

TIME 15         RECORD= 0
    MIN= 85        MAX= 123
  SUM= 5847     AVG BPM= 97 45

TIME 16         RECORD= 0
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  SUM= 5528     AVG BPM= 92 133

TIME 17         RECORD= 0
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  SUM= 6899     AVG BPM= 114 98
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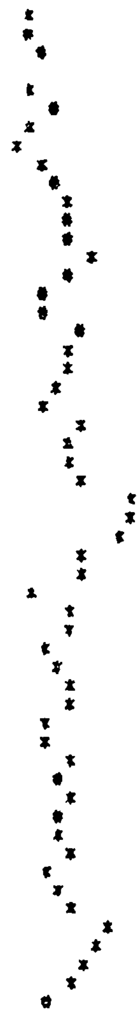

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 86*  1
 65* 32
102* 14
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 90*  1
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104*  1
113* 18
122*  1
119* 24
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136*  2
115* 73   9
 97* 21
102* 19  10
126* 14
124*  1
116*  1
109*  1
 99*  3
130*  1
115*  1
123*  1
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FIGURE 1. Medilog Data Printout

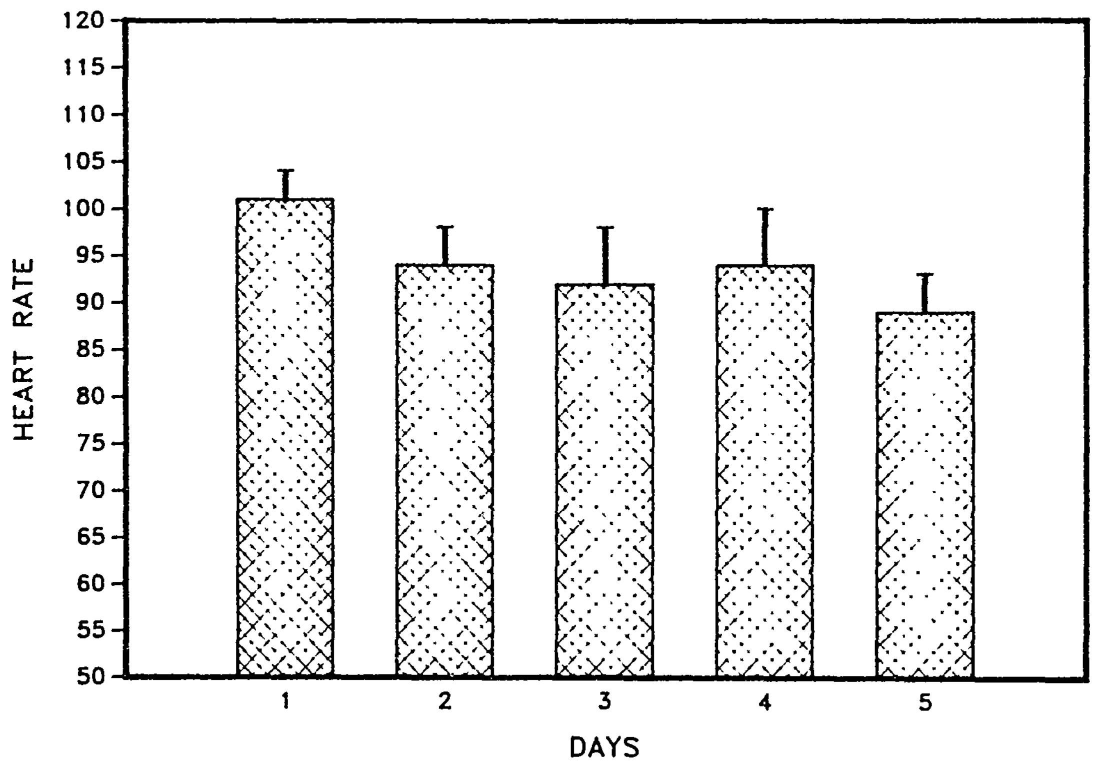

FIGURE 2. Heart rate response to five day scenario. Mean of four squads (17 hour active period).

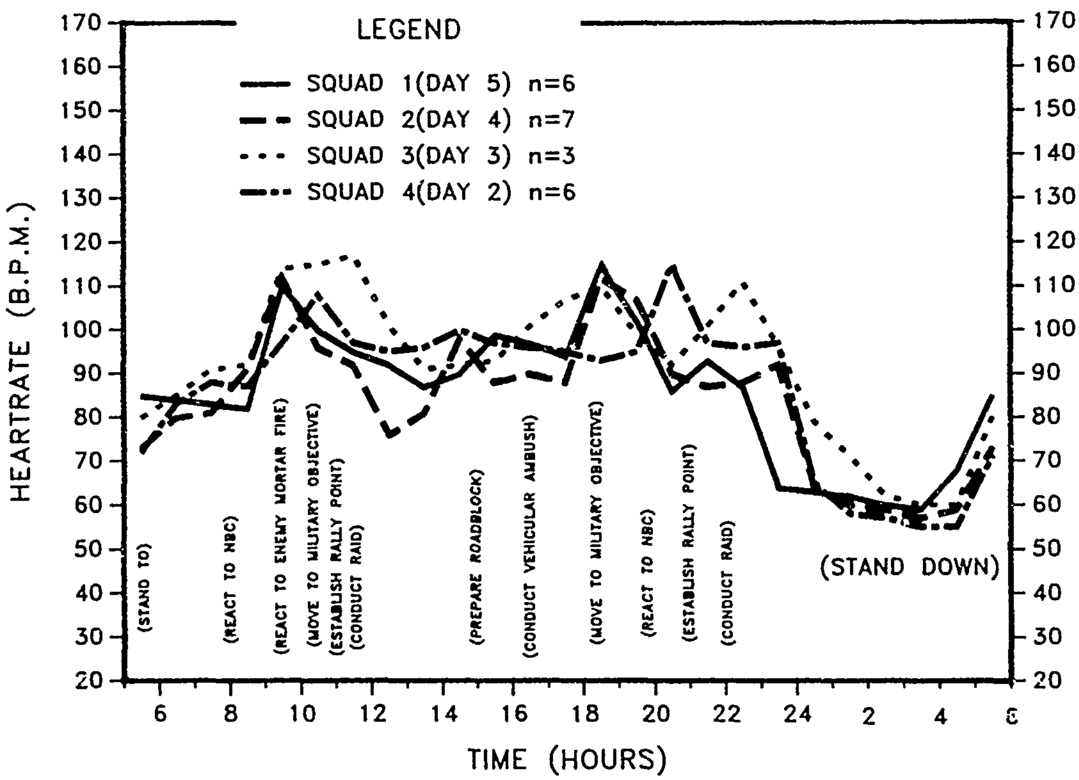

FIGURE 3. Quadrant one - heart rate/activity plot.

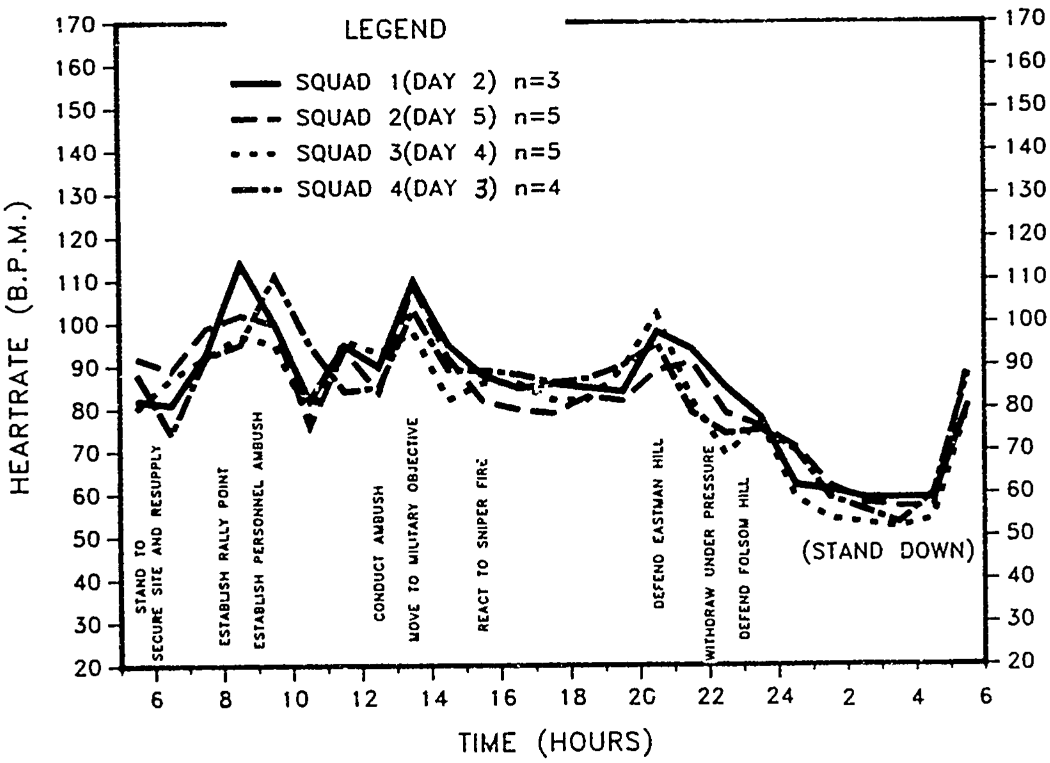

FIGURE 4. Quadrant two - heart rate/activity plot.

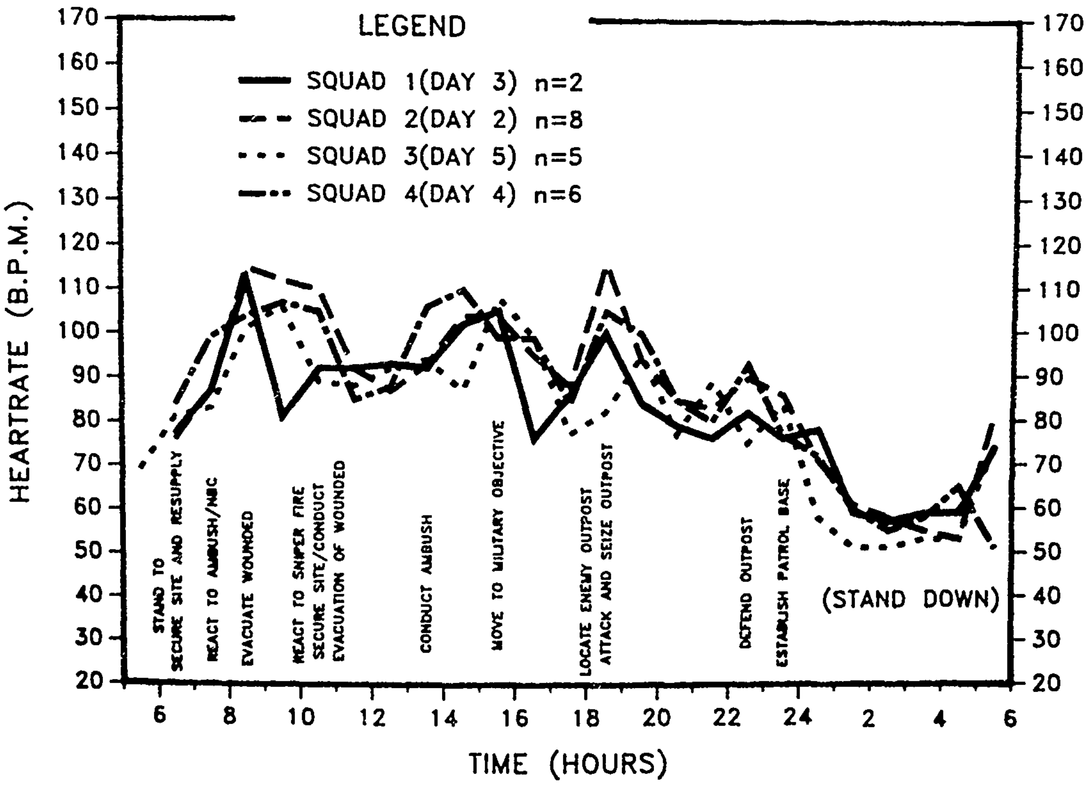

FIGURE 5. Quadrant three - heart rate/activity plot.

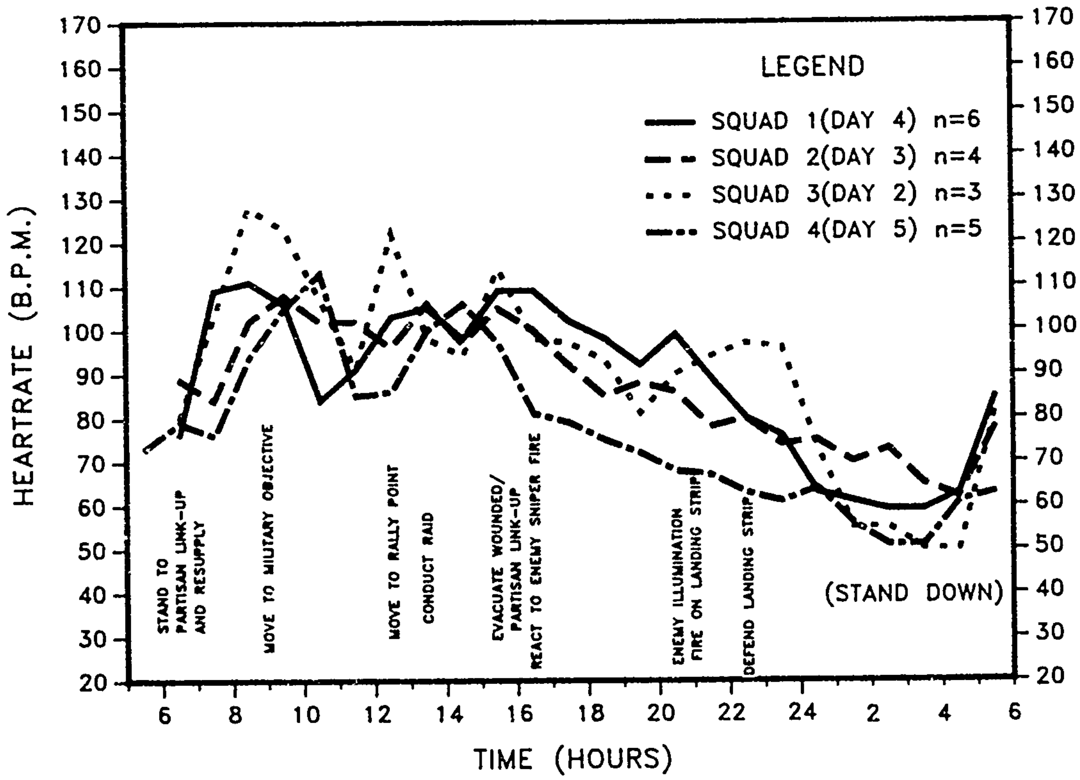

FIGURE 6. Quadrant four - heart rate/activity plot