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VENTILATORY REQUIREMENTS OF M1 TANK CREW MEMBERS DURING SIMULATED BATTLEFIELD CONDITIONS

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Minute ventilation (V_E) and heart rate values were recorded in armored vehicle crewmen during treadmill, armcrank, and a simulated loading experiment. The crewmen were found to have lower aerobic capacity but greater muscular efficiency than control subjects, but did not demonstrate greater upper body performance than controls. These results suggest that experiments loading ammunition in armored vehicles would not be restricted to trained crewmen. The laboratory experiment was followed by a field exercise in which tank crews performed strenuous loading exercises in order to simulate a defensive combat scenario. Minute ventilation, heart rate, and oxygen consumption were measured using Oxylog^R/Vitalog^R instrumentation. Mean maximal minute ventilation for loaders approximated 47 lpm, with a mean V_E of 35 lpm. Recommendations were made for incorporating V_E data into estimates of alveolar ventilation as a basis for estimates of carbon monoxide exposure utilizing the Coburn-Forster-Kane equation and for estimating peak inspiratory requirements when crewmen are utilizing supplied air systems.

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Mr. Robert Brewer, Industrial Services Branch, U.S. Army Biomedical Research and Development Laboratory, fabricated aircraft survival vests to accomodate the physiological instrumentation used in this study.

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1.0 PURPOSE AND OBJECTIVE

The Army requires an accurate understanding of combat vehicle crewmen's ventilatory requirements (1) to improve predictions of carbon monoxide hazards in armored combat vehicles (ACV)[1], (2) to evaluate the adequacy of ACV collective filtered air systems, and (3) to validate current methodology for predicting toxicity of combustion gases produced after ACV penetration by a threat munition. A comprehensive, 3-phase research protocol was formulated and implemented to determine ventilatory requirements of tank crewmen.

2.0 PROBLEM DEFINITION AND LITERATURE REVIEW

Studies of ventilatory requirements for armored vehicles crewmen are limited. Toner, et al evaluated physiologic responses in armored vehicle crewmen wearing various levels of MOPP (Mission Oriented Protective Posture) clothing during a 165 minute scenario[2]. When light exercise was performed at ambient temperatures of 90-100°F in MOPP III gear, the loader's heart rate was 185 beats per minute[2]. Use of climatic cooling equipment decreased heart rates[2]. In a subsequent study performed without thermal stress[3], crewmen performed a simulated tank firing exercise lasting 172 minutes, in which one round was loaded and restowed in the ready rack every 5.5 minutes. The loader's heart rate was only slightly elevated above those of the other crew members (101 beats/min versus an average of 82 beats/min for the other crewmen). The significant increase in heart rate in the former study illustrated an important synergistic effect between heat stress and workload.

The Canadian Defence and Civilian Institute of Environmental Medicine performed a laboratory study in which 12 untrained male volunteers (not tank crewmen) lifted dummy ammunition from the floor to a tabletop as a simulation of a tank loading exercise[4]. The subject was paced to lift one round every ten seconds, resulting in 15 repetitions over 2.5 minutes. The procedure was repeated 4 times with a 15 minute break between each run. The data are shown in Table 1:

Table 1. Mean and Standard Deviation of Alveolar Ventilation (V_A) During a Simulated Loading Exercise (lpm at BTPS).

	Resting	During Work	5-7.5 Minutes Post-Work
Range	5.3-10.3	9.8-14.6	6.2-10.7
Mean ± SD	8.0±1.4	11.8±1.6	8.7±1.2

Gill and Madill subsequently used these ventilatory rates to evaluate the hazard of the carbon monoxide to armored vehicle crewmen[5]. However, since the Canadians' field scenario ventilatory rates were only slightly above resting levels, the utility of their data to predict carbon monoxide hazards should be questioned.

These are the only studies known to the authors dealing specifically with work levels and resulting ventilatory requirements for tank crewmen. Toner's studies replicated the environment and activity[2,3], but did not measure ventilation whereas the Canadian study did not match the combat environment or activity[4]. Therefore, neither study produced information which would allow the estimation of tank crew ventilatory requirements.

The toxicology of carbon monoxide (CO) inhalation has been investigated for decades. Physiologic effects of CO exposure are caused primarily by the displacement of oxygen (O_2) from hemoglobin (Hb) and by disruption of the blood's O_2 carrying capacity. The affinity of CO for Hb is >200 times that of O_2, resulting in preferential formation of carboxyhemoglobin (COHb). Thus, exposure to very small concentrations of CO produces elevated COHb levels. Clinical effects of acute CO intoxication have been correlated with the level of COHb concentrations. Thus, by predicting probable levels of COHb from a physical measure of ambient CO concentration, human hazards for that measured environment can be determined.

The physical configuration and operational requirements of modern armored vehicles produce very high but transient ambient levels of CO in both training and combat[5], and therefore cause a significant risk of CO exposure. In 1981, the Army developed a modified version of the Coburn-Forster-Kane equation (CFKE)[6] to predict COHb levels in response to CO exposure in military scenarios and included this equation in MIL-STD-1472C[7] and MIL-HDBK-759A[8]. The military equation uses summed constants taken from a National Institutes of Occupational Safety and Health publication[9] to represent work effort levels. MIL-STD-1472C states that CO exposure levels should not exceed levels predicted to cause COHb levels >5% for aircraft personnel and >10% for personnel operating ground vehicles[7]. MIL-HDBK-759A assumes a work effort level with alveolar ventilation (V_A) = 24 L/min (called "Level 4") for all crew members during weapons firing and a work effort level associated with V_A = 18 L/min ("Level 3") for all other mission activities[8]. The source of these V_A values (bicycle ergometry) and the applicability to the work effort levels of armored vehicle crewmen have been controversial since the CO standard was officially adopted in 1981. Field measurements of ventilation during training or combat scenarios have not been performed to validate the assumptions in MIL-HDBK-759A. One purpose of this study was to measure crew ventilation needs which would allow realistic prediction of COHb values.

During training and combat, armored vehicle crewmen are often required to wear MOPP clothing. The respiratory protective equipment consists of facemask, air hose and filtration canister which is usually connected to the primary or backup forced air filtering system. Continuous forced air is supplied through the collective ventilation system to each crewman's mask to overcome significant airflow resistance and dead space within the system. Continuous positive mask pressure is additionally desirable to prevent inhalation of unfiltered air around the mask, when the soldier is fighting in a contaminated environment. Current design specifications for airflow appear to have been chosen without the benefit of measured physiologic data. The backup ventilation system specification states that each crewman must be provided with at least 3 standard cubic feet per minute (scfm) (84 lpm) of ventilatory air[10]. In 1986, the back-up ventilatory system was unable to meet these specifications, and the medical community was asked to provide detailed measurements of human requirements[10,11]. U.S. Army Medical Research and Development Command scientists already tasked to measure ACV crew ventilation requirements accurately to improve CO hazard predictions agreed to consider vehicle ventilation specifications as an additional issue[1].

Another use for this study is in estimating toxic inhalant exposures and resulting inhalation injuries. The U.S. Congress mandated a Joint Live Fire Test program to assess ACV crew survivability following armor penetration[12]. Certain "behind-armor" effects result in exposure to toxic gases such as oxides of nitrogen, acid halides and hydrogen cyanide. Current methods of predicting injury and incapacitation assume a 3-fold increase in ventilation for all crew members[13]. This study's measured ventilation rates were expected to improve the accuracy of the "behind-armor" toxic gas injury/incapacitation prediction criteria, by documenting working soldiers' ventilatory requirements.

APPROACH TO THE PROBLEM

Work performed by tank crew loaders exceeds that of the other crewmen and involves primarily upper body exercise. Such exercise possesses unique physiologic characteristics. For example, most individuals experience fatigue earlier with arm exercise (arm cranking) than with lower extremity exercise (treadmill or bicycle ergometry)[14,15]. Pimental, et al. described significant reduction in maximal oxygen uptake (VO_2max), decreased maximal exercise time, and increased ventilatory requirements for oxygen for upper body exercises[16]. Pandolf, et al. observed higher ratings of relative perceived exertion (RPE) during upper body exercise[17]. Despite the increased oxygen cost of arm exercises, a training effect occurs with some activities, such as swimming[18]. Exercise tolerance is most affected by physical conditioning and by individual variation[19]. Exercises involving multiple body movements (free-form work, such as that performed by tank crew loaders) are substantially more complicated than arm cranking. Data on measurement of free-form exercise, particularly for the upper body, could not be found in the literature. The maximal respiratory needs for any occupation can be optimally defined by studying a precise duplication of the activity[19]. Therefore, Medical Research and Development Command investigators devised a protocol to measure tank crewman ventilation requirements during a realistic, combat training, firing sequence.

3.0 MATERIALS AND METHODS

3.1 MILITARY SCENARIO

A defensive combat scenario was identified as the collection of military tasks which would create the greatest physical demand for the tank crew, especially the loader. The U.S. Armor and Engineer Board (USAARENBD) concurred with the use of this scenario[20]. The defensive combat scenario is characterized by an overwhelming number of enemy targets which requires the tank crew to identify, target and shoot in rapid sequence. Typically, doctrine requires a limited number of engagements from the firing position (usually hull defilade) before the tank must pull back to prevent being engaged by the enemy. Firing rate and duration are influenced principally by the availability of ammunition. In the M1 tank, twenty-two rounds are available in the ready rack, twenty-two rounds are available in the semi-ready rack and 11 rounds are stored in the turret floor and hull (the three rounds in the turret floor are immediately available for firing). Firing activities stop intermittently to allow ammunition transfer from the semi-ready rack and hull storage locations. Sustained firing activities are limited to 25 rounds before redistribution activities must take place (FM 17-12-1)[21], and therefore this firing sequence would maximally stress the loader.

Several modifications to this idealistic combat scenario were adopted to meet tank gunnery scoring requirements, range capability at Ft. Knox, ammunition availability, and safety requirements. The level of crew proficiency was also a limiting factor. The gunnery scoring requirements and number and types of targets presented were set by the USAARENBD from FM 17-12-1 and modified to meet range capabilities. Target presentations and associated scoring guidelines are outlined in Appendices 1 and 2.

The USAARENBD had originally planned to provide experienced crews for this study. During final preparations, only composite crews were available (experienced individuals who had not previously worked together). Based upon safety considerations in the use of composite crews, movement back and forth to the firing line was eliminated. Ammunition was stored and fired in two categories (all sabot were fired, followed by all high explosive anti-tank (HEAT) rounds) instead of mixed, as would be done in a realistic situation. Cost restrictions limited the study to a total of 300 rounds. To obtain 8 replications, the ammunition was distributed to each vehicle as 19 rounds of sabot in the ready rack and 18 rounds of HEAT in the semi-ready rack. A typical scenario is described in Table 2.

Table 2. Chronology of a Typical Test Scenario Worksheet

EVENT	ELAPSED TIME (min:sec)	COMMENT
Upload ammunition	0:45	No physiologic measurements
Equip crew with Oxylog/ Vitalog	1:15	No physiologic measurements
Move tank to firing line	1:30	Turn on instruments at firing line
First firing sequence	13:11	Fire 19 rounds of sabot
Redistribute ammunition	33:11	Ammunition moved from semi-ready to ready rack
Second firing sequence	40:57	Fire 18 rounds of HEAT
Terminate scenario	41:15	Recover instrumentation

3.2 INSTRUMENTATION

The Oxylog®/Vitalog® combination apparatus was chosen because of its reasonable accuracy and portability for field measurements of minute ventilation (V_E) and oxygen consumption (VO_2). The Oxylog® (P.K. Morgan Instruments Inc., Andover, MA) measures V_E and VO_2. The Vitalog® PMS-8 (Vitalog Corporation, Redwood City, CA) monitors heart rate and ambient temperature and contains a recorder which stores Oxylog® and Vitalog® output data. At the end of each measurement session, the data were transferred to a computer system for storage and statistical analysis. To determine relative humidity, wet and dry bulb temperatures were recorded separately inside each vehicle with a Metrosonics HS-371 thermometer® (Metrosonics Inc., Rochester, NY). Calculation of relative humidity utilized the method of Duttfield and Nastrom (Table 10). The calibration procedure of the Oxylog®/Vitalog® system was performed according to manufacturer's guidelines[22] at the beginning of each experimental day. Oxylog® data are reported at ambient pressure for dry gas at standard temperature (ATPD).

In 1981, the Oxylog® system was compared to reference laboratory methodology and found accurate within 5.6% on VO_2 measurement and totally accurate for V_E measurement[23]. Each of the 6 Oxylog®/Vitalog® units used in this experiment was standardized (calibrated) by comparing it to a Tissot spirometer prior to Phase II of the protocol. Testing of each unit consisted of 9 or more steady state exercise trials in which several subjects performed arm crank ergometry against constant workloads of 25-37.5 watts. Submaximal exercise tasks were chosen to allow subjects to achieve steady state levels of V_E and VO_2. Variations within and between subjects were compared (Appendix 3). V_E and VO_2 were (1) recorded from the Oxylog® display panel, (2) recorded from the Vitalog® memory by data transfer to an Apple IIe® computer system (Apple Computer Inc., Cupertino, CA), and (3) calculated from bell displacements measured with a Collins 120 Liter® (Tissot) spirometer (Warren E. Collins, Inc., Braintree, MA). Oxylog®, Vitalog®, and Tissot-measured V_E and VO_2 were compared, and Vitalog® correction factors were calculated by utilizing Tissot values as the "standard". To calculate the Tissot derived VO_2, mixed expired gases were evaluated for F_EO_2 and F_ECO_2 utilizing the Ametek S-3A/1 O_2 analyzer® and Ametek CD-3A CO_2 analyzer® (Ametek, Pittsburgh, PA) respectively. VO_2 and V_E were calculated from the following equations:

$$VO_2 = \frac{1 - (F_EO_2 + F_ECO_2)}{1 - F_IO_2} \times (F_IO_2 - F_EO_2) \times V_E \text{ (ATPD)}$$

where

F_EO_2 = fraction of O_2 in the mixed expired air sample

F_ECO_2 = fraction of CO_2 in the mixed expired air sample

F_IO_2 = fraction of O_2 in the inspired air sample (0.2093)

$\frac{1 - F_EO_2 - F_ECO_2}{1 - F_IO_2}$ = correction factor to account for small differences in inspired and expired volumes

and

$$V_E \text{ (ATPD)} = V_E \text{ (BTPS)} \times \frac{P_B - P_{H_2O}}{P_B} \times \frac{273}{273 + T}$$

T = temperature of the expired air at the Oxylog® mask (°C)

P_{H_2O} = $31.3 - 1.8T + 0.06T^2$

Humidity and temperature effects were accounted for by measuring these variables and correcting recorded data as needed[22]. The original Oxylog® masks were found to leak significantly during trials, especially when subjects were performing physical activities. The problem was resolved by installing the Oxylog® inspiratory flowmeter and expiratory collecting hose inside the standard U.S. Army M-25 tanker's mask (Figure 1). Inspiratory leaks were markedly reduced, thus improving the accuracy of V_E measurements. With vigorous activity, minimal expiratory leaks occurred, but did not affect measurement of V_E or VO_2. The modified masks used throughout the protocol were thoroughly cleaned with alcohol between subjects.

3.3 EXPERIMENTAL DESIGN

This human use protocol was approved by the U.S. Army Medical Research and Development Command and the U.S. Army Office of the Surgeon General prior to its initiation. The experiment was accomplished in three phases. In Phase I, tank crew members were observed firing tank weapons at Ft. Knox, Kentucky. These observations allowed the researchers to devise simulated loading exercises for Phase II and construct firing scenarios for Phase III.

Phase II was performed at the Department of Respiratory Research Laboratory, WRAIR. All subjects were thoroughly counselled and signed a Volunteer Agreement Affidavit (DA Form 5303-R) before entering the study. Eight subjects were volunteer tank crew loaders from Fort Knox; the six controls were soldier volunteers assigned to WRAIR. Due to the limited availability of volunteers, loader and control populations were not matched for age, weight, height, smoking history or other physiologic variables. Because significant numbers of military personnel smoke, cigarette smokers were included as study participants. The preselected age range was 18-32 years. Individuals who regularly performed recreational upper body exercises such as weight lifting, swimming, or rowing were excluded from the study. Before exercising, each volunteer completed a medical history questionnaire (Figure 2), underwent complete physical examination, and obtained a resting 12-lead electrocardiogram (Sensormedics ECG Horizon System[R], SensorMedics Corp., Anaheim, CA). No individual was identified as having sufficient cardiopulmonary disease to eliminate him from the study. Because the exercise tasks were no more strenuous than routine military tasks (such as the Army physical fitness test), no additional medical evaluation was required. Pertinent data recorded during the physical examination included subject age, height and weight. Total body fat percentiles were calculated from triceps skin fold thickness measurements taken with the Lange Skinfold Calipers[R] (Cambridge Scientific Industries Inc., Cambridge, MD) utilizing standard methodology[24]. Atmospheric pressure measurements were recorded daily with a mercury barometer.

Subjects were studied on three consecutive mornings in a nonfasting state to simulate normal work conditions. Testing was performed in an environmentally controlled building. On day 1, subjects underwent routine spirometric testing utilizing a SRL M10-0473 Automated Spirometer[R] (SRL Controls Div., Dayton, OH) and disposable mouthpieces, to reveal any baseline abnormalities of pulmonary function. At least three forced vital capacity (FVC) maneuvers were performed. To provide test accuracy, the sum of the FVC and the forced expired volume in one second (FEV_1) had to agree within 5% on three determinations. Exercise testing protocols then began. Subjects were evaluated with continuous cardiac monitoring with a Lifepak 6 Monitor-Defibrillator[R] (Physio-Control Inc., Redmond, WA) to detect occult cardiac disease and with the Oxylog[R]/Vitalog[R] system to record heart rate, minute ventilation and oxygen consumption every 20 seconds.

Arm crank exercise was performed on seated subjects utilizing a Monark Rehabilitation Trainer ergometer[R] (Monark-Crescent AB, Varberg, Sweden) mounted on an adjustable table and positioned at heart level. Because subjects were not firmly secured to the chair, exercise actually involved the entire upper body musculature rather than being isolated to the arms. Each subject maintained the crank rate of 70 revolutions per minute, previously shown to maximize oxygen uptake[25]. The power output began at 35 watts and increased by 35 watts every 3 minutes until the maximal voluntary level had been reached. Although the literature does not describe a "standard" protocol for upper body exercise, this protocol is similar to previous reports[26].

On day 2, lower body exercise was evaluated utilizing a Quinton DOC19 treadmill[R] (Quinton Instruments, Seattle, WA). A modified Bruce protocol[27] was performed to maximal exercise tolerance in soldiers wearing standard battle dress uniforms (BDUs) and Army boots. According to Jones' textbook on clinical exercise testing[28], the Bruce protocol can be satisfactorily used in fit subjects. Vitalog[R] units were used to determine maximal heart rate achieved, because motion artifacts invalidated Lifepak 6[R] recorded data. Age predicted maximal heart rates were calculated as:

$$HR_{max} \text{ (beats/minute)} = 210 - .65 \text{ (age)}^{27}$$

Predicted maximal VO_2 values utilized the following regression equation[28]

$VO_2max = 3.45 * Ht(m) - 0.028 * A(yr) + 0.022 * Wt(kg) - 3.76$.

The treadmill task was included in the protocol to determine whether loaders' upper body fitness exceeded their lower body fitness, compared to a control population. Stages of the Bruce protocol[27] are shown in Table 3:

Table 3. Stages of the modified Bruce Treadmill Exercise Protocol.

Stage #	Speed (mph)	Grade (%)	Duration (min)
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.8	20	3
7	6.6	22	3

The mock-up loading protocol was performed on day 3 of testing, and followed criteria developed in Phase I. This exercise task was the least stressful portion of Phase II. The firing scenario was performed with subjects intermittently seated on an adjustable stool similar to their normal position in a tank. Subjects lifted "dummy", HEAT rounds, average weight 20 kg, from an ammunition rack positioned approximately 36 inches above the floor, then maneuvered the rounds onto a plywood mock-up "gun breech" placed 46 inches in front of the ammunition rack. The "dummy" rounds' dimensions were identical to live HEAT rounds. Distances between the breech and ready rack and height above the floor were identical to M1 Abrams tank dimensions. Twenty rounds were "loaded" into the mock-up gun breech at 8 second intervals to simulate rapid firing of almost all ammunition stored in the ready rack of the M1 tank. The protocol did not duplicate internal redistribution or resupply of tank ammunition. Figure 3 shows an instrumented soldier performing the mock-up exercise.

For each exercise task except the mock-up protocol, maximal exercise was determined by the subject's inability to continue. A rating scale for perceived exertion (RPE) was completed after each task (utilizing the open-ended Borg Scale shown in Figure 4), to determine the subject's degree of skeletal muscle (M), cardiopulmonary (C), and generalized (G) fatigue at the termination of exercise[17]. In addition, the physician investigator monitored each subject for chest pain, syncope, or electrocardiographic evidence of myocardial ischemia (ST segment depression of equal to or greater than 1 mm or significant ventricular arrhythmias) during each exercise task. Phase II data from each exercise task were evaluated statistically with the two sample T-test assuming a common variance, and compared mean values between loader and control groups. Statistical significance was assumed to be present if $p \leq .05$.

Phase III was performed at Fort Knox during the last week of September 1988. Each crew member was studied only once, during the performance of a modified Table VI tank exercise as previously described. Of the 31 participating crewmen, 25 were monitored. Limitations in the number of Oxylog®/Vitalog® units and field damage to monitoring equipment prevented instrumentation of all study participants. The monitored group consisted of 8 loaders, 8 tank commanders, 4 gunners, and 5 drivers. The loader's hatch was in an open position during firing sequences. Minute ventilation, oxygen consumption and heart rate were measured by the Oxylog[R]/Vitalog[R] equipment.

The investigators calibrated equipment daily in the field. Each Oxylog[R]/Vitalog[R] unit was adjusted to barometric pressure and calibrated with 100% nitrogen gas at the start of each day. Study subjects wore BDUs together with modified tank crew masks. A modified, Army aviation survival vest worn over the BDUs was used to secure the Oxylog[R] and Vitalog[R] units, connecting cables and exhalation hose. Communication between crew members occurred via microphones built into the tank crew masks. Continuous audiovisual tape recordings of the loader were obtained during each field exercise scenario. Each tape was prepared with digital time display to be used for event-time correlations with Oxylog[R]/Vitalog[R] recordings. Phase III data comparing the different crewmen were not subjected to statistical analysis, because the protocol had been designed to place very different workloads on the various crew members. However, loaders' field performances were compared statistically to their laboratory testing.

4.0 FINDINGS

4.1 LABORATORY TESTING (PHASE II)

The 14 soldier volunteers in study Phase II included 6 WRAIR control subjects and 8 tank crew loaders from Fort Knox. All characteristics of the 2 groups were compared statistically (Table 4). All subjects denied a known history of serious cardiopulmonary diseases. Subject ages and weights were similar. Loaders were shorter with higher mean percentile of body fat, but differences were not statistically significant. Cardiac abnormalities were the only abnormal physical findings detected. In 1 control subject, frequent premature beats were noted, and in 2 loaders, minimal heart murmurs compatible with mitral valve prolapse syndrome were auscultated. Baseline spirometric tests in all subjects were compared to predicted values and were normal with no statistical difference between the control and loader groups. Six of 8 loaders smoked cigarettes, while no control subject smoked. Resting electrocardiograms revealed clinically unimportant abnormalities in 3 controls; 2 with left axis deviation and 1 with frequent premature atrial and ventricular contractions. All loaders had normal EKG tracings.

PHASE II - ARM CRANK EXERCISE

Table 5 contains all pertinent data and statistical analyses from the arm crank protocol. Control subjects exercised slightly longer and achieved similar levels of maximal heart rate (Figure 5) and maximal V_E (Figure 6) compared to the loaders (i.e. no statistical significance). All raw ventilation data were corrected by the calibration factor determined for the Oxylog[R] system (#359) used throughout Phase II. Mean values for maximal VO_2/kg ($p < .01$) and total VO_2/kg ($p < .01$) were statistically greater in the control subjects. Figure 7 shows meaned values for total VO_2/kg during arm crank exercise. When total VO_2/kg measurements were adjusted for differences in workload performed (Oxygen Efficiency = Workload/ VO_2/weight) and compared between loader and control groups (Figure 8 and Table 5), statistical significance persisted ($p < .05$). Percent of predicted maximal VO_2 achieved showed the controls had exercised to significantly higher levels ($p < .01$). Figure 6 suggested a ventilatory plateau at the highest workloads, though no similar pattern was discernible from heart rate or total VO_2/kg data (Figures 5,7). Ratings of perceived exertion for muscle (M), cardiopulmonary (C) and generalized fatigue (G) were assessed (Table

6). Mean data demonstrated significantly higher values for M, C and G for the controls.

PHASE II - TREADMILL EXERCISE

Treadmill exercise using the Bruce protocol was compared between loader and control groups and the data evaluated statistically (Table 7). Control subjects achieved slightly longer exercise duration and percentage of age-predicted heart rate than loaders, although differences were not significant. No differences in maximal heart rate (Figure 9) or maximal V_E (Figure 10) were found. Maximal VO_2/kg calculations showed statistically higher values for controls subjects ($p = .05$). Workload/max VO_2/kg and workload/Total VO_2/kg calculations demonstrated statistical significance ($p < .01$). The graph (Figure 9) relating heart rate to workload demonstrated remarkable linearity, whereas V_E vs workload (Figure 10) showed a definite ventilatory plateau after 10 minutes. Although the Oxylog's[R] calculation of VO_2 depends upon V_E, significant flattening of VO_2/kg vs workload (Figure 11) was not observed. Figure 12 illustrates the highly significant difference in oxygen efficiency between the two subject groups. Mean RPE values for treadmill testing were higher for control subjects (Table 6), although not statistically significant.

Because no symptoms of cardiac disease, significant arrhythmias, or ST segment depression occurred during treadmill testing, no subjects were stopped for medical reasons. The control subject found to have an asymptomatic arrhythmia both at rest and exercise was referred for subsequent cardiologic evaluation.

PHASE II - MOCK-UP EXERCISE

The mock-up exercise protocol presented an identical workload to all subjects, although work performed was not quantified. All measured cardiopulmonary data were tabulated and statistically analyzed in Table 8. Mean values for heart rate, V_E, max VO_2/kg, and % of predicted VO_2max achieved, and total VO_2/kg were statistically similar between the control and loader groups (Table 8 and Figures 13-15). For all subjects, measured cardiopulmonary parameters during the mock-up study were lower than values from the preceeding maximal exercise tasks. Mean RPE values demonstrated statistically significant differences, with control subjects choosing values of 11.2, 11.8, and 11.6, while tankers assigned values of 7.9, 9.6, and 9.6 (Table 6).

PHASE II - SUMMARY OF FINDINGS

In the control group, mean maximal heart rate was 194 with treadmill, 174 with arm crank and 144 with mock-up. In the loaders, corresponding values of 182, 167 and 144 were recorded. For max V_E, control values were 56.3, 53.7 and 35.3 l/min, while the loaders demonstrated 55.3, 50.1 and 38 l/min. Oxygen efficiency calculations (Workload/Total VO_2/kg) for treadmill and arm crank exercise were 307 and 270 kpm/ml/kg for controls and 388 and 327 for loaders.

4.2 PHASE III - FIELD STUDY

In study Phase III, soldiers wearing monitoring equipment were evaluated during the live-fire scenario discussed previously. During the exercise, significant Oxylog[R] damage was sustained inside the tanks and some data were lost. O_2 consumption measurements were most affected, being recorded for only 4 of 8 loaders (Table 11). However, at least partial data sets measuring V_E and heart rate were obtained from 7 loaders, 8 tank commanders, 5 drivers and 4 gunners. All Phase III data were subsequently corrected (1) by multiplying by each Oxylog's[R] calibration factors (determined with the Tissot spirometer and listed in Table 9) and (2) by utilizing a calibration graph from the Oxylog[R] instruction manual[22] to account for variations in temperature and humidity (Table 10). Following each crew's completion of the firing scenario, RPE values were obtained. Approximately half of the tank crewmen were asked to compare their subjective impression of the work of breathing while using the Oxylog[R] apparatus to that using MOPP equipment attached to the blower system. All subjects complained the Oxylog[R] system required greater inspiratory effort.

Firing scenarios were graded by Ft. Knox personnel. Satisfactory target engagement by the tank crew was judged to occur when the engagement was completed in one minute. (By comparison, experienced crews are allowed 40 seconds.) Scores by tank crew are listed in Appendix 2. Six engagements were fired for each firing sequence, with each engagement consisting of 3-4 rounds. Firing scenarios were divided into 3 discrete parts: first firing sequence, internal redistribution, and second firing sequence. Crews 1-5 and 8 fired sabot rounds during the first firing sequence and the longer, heavier HEAT rounds during the second sequence. Crew 6 fired all sabot and crew 7 fired all HEAT. Investigators precisely determined different portions of the scenario, by comparing Vitalog[R] recordings with time displays on the audiovisual tapes. After reviewing engagement scores, loader activities and Vitalog[R] recorded physiologic data, firing sequences <13.5 minutes were selected for further evaluation in the study. Ten of 16 firing sequences were considered satisfactory based on these criteria. Calculated firing rates ranged from 1.33 to 2.16 rounds per minute.

Figures 16 and 17 show sequential measurements of heart rate and V_E occurring during a typical firing scenario (Crew #5). Each crewman is identified, and firing and internal redistribution phases are labelled. The gunner's cardiopulmonary parameters increased briefly during internal redistribution, when he substituted himself for the loader. The tank commander assisted throughout internal redistribution and developed increased V_E and heart rate.

To study cardiopulmonary responses to <u>maximal</u> workloads, investigators recorded values of heart rate, V_E and VO_2 during the maximal minute of each firing sequence completed in <13.5 minutes (Table 11). For loaders, maximal work occurred during the most rapid firing of the firing sequences. Drivers' and gunners' work, on the other hand, usually maximized soon after the tanks were positioned on the firing line. Tank commanders worked hardest during internal redistribution, if they chose to assist their loaders. Loaders' mean values were computed and compared to values recorded during the Phase II laboratory tasks (Table 12). Table 11 additionally lists maximal physiologic responses of all other crewmen studied. During all phases of firing, loaders worked significantly harder than other crew members.

Besides calculating cardiopulmonary responses to maximal physiologic stress in the field, responses to average workloads were evaluated. Figure 18 shows loaders' average heart rate versus tank firing rates for acceptable firing sequences, and Figure 19 depicts similar treatment of V_E data. Each graph demonstrates a rough relationship between increasing firing rates and progressive elevation in cardiopulmonary measurements. Both graphs also demonstrate a tendency toward more rapid firing during second firing sequences, probably related to increased familiarity with target appearances and locations gained during the first sequences. Mean heart rates were calculated by averaging all values recorded during acceptable firing sequences. Figure 20 shows that mean heart rates varied according to crew position, with the loaders' heart rates being highest. In a related analysis, V_E data (Figure 21) from acceptable firing sequences were totalled and sorted by crew position. Figure 21 demonstrates increased total ventilation in loaders compared to the other crewmen. VO_2 measurements obtained during Phase III (Table 11) are reported only for the 4 loaders, who were monitored with the same Oxylog® system used for the laboratory study. VO_2 data from other crewmen (wearing other Oxylogs®) were not reported, because of wide variation in equipment accuracy demonstrated during calibration (Appendix 3). Table 12 summarizes loaders' maximal cardiopulmonary responses for all 4 exercise tasks.

5.0 DISCUSSION

5.1 LABORATORY TESTING (PHASE II)

This study's laboratory phase was designed (1) to validate the Oxylog®/Vitalog® system and (2) to define physiologic demands of maximal upper and lower body exercise and (3) to determine maximal ventilatory requirements for simulated ammunition loading of the M1 tank's main gun. Calibration of the Oxylog®/Vitalog® systems demonstrated errors ranging from 6% undermeasurement to 38% overmeasurement of V_E (Appendix 3). However, repeated V_E measurements on each unit demonstrated minimal within unit variation (i.e. internal consistency). VO_2 measurement errors ranged from 18% under to 49% over and were internally consistent for 4 of 6 units (Appendix 3) . In 3 of 6 units, Vitalog® recorded VO_2 values were significantly less than oxygen analyzer measured values taken from Tissot samples. Because a reliable unit (#359) was used for all Phase II studies, we believe VO_2 data can be compared between the different exercise tasks and between the loader and control groups for this part of the protocol. Phase II testing also conclusively demonstrated that the Oxylog® system cannot reliably measure V_E levels exceeding 55-60 l/min. Although the Oxylog® instruction manual states the Oxylog® can accurately record V_E values up to 80 lpm[22], our data demonstrate a more significant limitation in maximal capability. This phenomenon is best illustrated by the treadmill data (Figure 9,10), which show flattening of V_E at a time when heart rate was increasing steadily. The recorded response is not physiologic, and represents an error induced by equipment limitation. Arm crank exercise data reveal a similar but less pronounced effect on V_E (Figure 5,6). Further evidence of Oxylog® measuring limitation can be deduced from the knowledge that normal subjects' maximal exercise ventilation approximates 65-70% of their maximal voluntary ventilation (MVV). MVV itself can be estimated as 35 * FEV_1. Using these formulae, subjects' predicted MVV should have been 145 l/min and predicted exercise $V_E$max 95-100 l/min. However, Tables 5 and 7 show that max V_E measurements did not even approach predicted maximal values. Because the Oxylog® calculates VO_2 by multiplying V_E by the difference between ambient and expired pO_2, VO_2 measurements also become inaccurate when V_E exceeds 60 l/min. Finally, equipment limitations prevented field estimation of anaerobic threshold, since a sharp increase in V_E relative to VO_2 could not be demonstrated. To summarize, comparison of Oxylog® calibration data with previous reports[23] revealed a large discrepancy between measured and reported accuracy.

Cigarette smoking history was evaluated as part of the original health questionnaire. Six of 8 loaders were current, regular cigarette smokers, while none of 6 controls smoked. Persons currently performing regular, upper body exercises (swimming, weight lifting, etc.) were excluded from the study. During laboratory exercise testing, tank crew loaders were found to have superior efficiency of oxygen utilization but lower endurance than control subjects.

Although one might assume that loaders regularly lift large numbers of heavy rounds, actual handling of ammunition is reported to occur only during field exercises, which are infrequent due to expense and limited access to firing ranges. Physical conditioning of tank crewmen therefore parallels that of other soldiers.

Pandolf, et al[17] have studied the perception of exertion among exercising subjects. They have developed a rating system to determine why individuals stop exercising, and have shown in fit subjects that maximal upper body exercise is usually limited by muscle fatigue whereas lower body exercise is limited by generalized or cardiopulmonary exhaustion[17]. When our study and control groups were compared, several interesting findings were documented. For each exercise task, control subjects chose higher RPEs (Table 6). The differences between the groups were statistically significant for arm crank and mock-up exercise. While control subjects' higher RPEs could possibly be ascribed to inferior physical fitness, they are more likely due to the controls' greater efforts or to their more realistic self assessment skills. As expected, both groups' arm crank exercise produced higher "muscle fatigue" RPEs than "cardiopulmonary" RPEs, whereas treadmill exercise showed opposite results (Table 6). These data support the theory of arm crank limitation by local factors (i.e. lactic acidosis) and treadmill limitation by the cardiopulmonary fatigue[17].

When we compared data from the mock-up portion of our study to Canadian Defense Institute data listed in Table 1, we found mean levels for maximal V_E in our study exceeding 35 l/min in both controls and loaders (Table 8). The Canadians reported that V_A increased from 8.0 to 11.8 l/min[4]. V_A is computed from minute ventilation and ventilatory frequency according to the following formulae[29]:

$$V_A = V_E - f * V_D$$
$$V_D = 132 + (0.067 * V_T)$$
$$V_A = (0.933 * V_E) - (132 * f)$$

where: V_A = alveolar ventilation per minute
V_E = minute ventilation
V_T = tidal volume per breath
V_D = dead space volume per breath
f = respiratory frequency per minute

This formula can be simplified by use of the following approximations:

$$V_A = 0.75\ V_E \text{ (sedentary)}$$
$$V_A = 0.85\ V_E \text{ (exercise)}$$[28]

Since V_A measurements cannot be obtained in the field due to methodological obstacles, V_E can be measured and V_A estimated from the above equations. Assuming V_A is approximately 85% of V_E[28], our calculated V_A values would have been approximately 30 lpm. We conclude our mock-up exercise was much more physically demanding than the Canadian's, because of (1) the more rapid rate of lifting the rounds and (2) the more complex muscular movements (e.g. rotation, lifting, bending, extending, etc.) required by our protocol.

To compare exercise intensity achieved by the 2 groups of soldiers, predicted VO_2max values were calculated for each individual utilizing a regression equation based on height, age and weight[28]. The predictive equation was developed for cycle ergometry. On average, arm crank VO_2max approximates 73% of the cycle ergometry value[26]. Predicted arm crank VO_2max values were divided by body wt (kg) and compared to measured maximal VO_2/kg values as a percent predicted for each exercise task. Results for each Phase II exercise task are displayed in the pertinent tables (5,7,8). Differences between mean VO_2max/kg values achieved and % predicted were highly statistically significant for arm crank and treadmill exercise, and demonstrated that control subjects consumed more O_2/kg while achieving similar maximal exercise levels. Three possible explanations for reduced loader VO_2max/kg are (1) lowered motivation, (2) lowered overall physical fitness, and/or (3) a consequence of cigarette smoking.

5.2 FIELD TESTING (PHASE III)

In study Phase III, we were able to compare loaders' performances during the live fire scenario (Tables 11,12) to their laboratory responses (Tables 5,7,8). During maximal exercise in the tanks mean ventilation and heart rate values were significantly greater than those recorded during the mock-up scenario and similar to maximal arm crank exercise values. Maximal ventilatory rates for most loaders were within the 55-60 lpm range, previously shown to be accurately recorded by the Oxylog® system. Treadmill values for maximum measured V_E and VO_2 were significantly greater than field or upper body exercise values. Heart rate and ventilatory measurements closely paralleled each other for each exercise task. Overall, tank commanders, gunners and drivers demonstrated only mildly increased heart and ventilatory rates during firing. The crewmen who assisted loaders during internal redistribution did increase their heart and respiratory rates (Figures 18,19). However, we must emphasize that our protocol was designed to stress loaders maximally, while the other crewmen (particularly the drivers and gunners) performed minimal activity. Because of the Oxylog® calibration problems previously discussed, only loaders' Phase III VO_2 data were evaluated (Table 12). They were found comparable to arm crank values.

Calculation of loaders' average ventilatory and heart rates during firing sequences showed a rough correlation between increasing V_E and heart rate and increasing firing rates (Figures 18,19). Figure 19 further demonstrates that the 3 highest ventilatory loads occurred during the second firing sequences for tank crews 4, 5 and 7. We cannot determine whether this finding resulted from firing longer, heavier HEAT rounds (i.e. increased workload) or from fatigue caused by earlier exertion. An additional factor likely contributing to the more rapid, second firing sequences was the learned behavior gained during the first sequences. Because identical targets were presented in both sequences (the order of target presentations did vary), it was easier to locate them the second time. Mean ventilatory rates ranged as high as 50 lpm during the most rapid firing sequences. Comparison of average heart rates and total ventilation by crew position (Figures 20,21) also demonstrated greatly increased cardiopulmonary responses in loaders compared to the other crewmen. Figures 16 and 17 provide another way of comparing tank crewmen's heart and ventilatory rates by sequentially depicting changes which occurred during a representative firing scenario (Crew #5).

We have identified a number of unquantified factors which may have influenced or can potentially influence ventilatory measurements. The respiratory circuit (modified tanker's mask and Oxylog® unit) used throughout the protocol caused some degree of inspiratory and expiratory resistance to airflow. Both resistances increase progressively as airflow rates increase[30]. Therefore, subjects' work of breathing increased along with their levels of physical activity. We did not measure workloads induced by the respiratory apparatus, but assume a small unmeasured effect on V_E. Additional wartime stresses such as full MOPP clothing and fear would also increase ventilatory and cardiovascular requirements. Although we cannot precisely determine these factors' effects on cardiorespiratory function, we consider the study data a reasonable approximation of battlefield responses during a defensive scenario.

5.3 CALCULATION OF ALVEOLAR VENTILATION AND ESTIMATION OF PEAK VENTILATION

After correcting the raw data for errors in Oxylog®/Vitalog® measurements (Tables 7,8) and assuming alveolar ventilation V_A to be 85% of V_E, V_A values were calculated for the various crew positions. We evaluated the firing sequences which lasted <13.5 minutes and measured maximal V_E values. The V_A calculations were compared with the alveolar ventilation requirement of 24 lpm specified (e.g. for all tank crewmen during firing scenarios) in para 3.7.5. of MIL-HDBK-759A when evaluating soldier exposure to CO[8]. Basing V_A values on mean ventilatory requirements during rapid firing sequences resulted in values of 30 lpm for loaders, 16 lpm for tank commanders, 9 lpm for drivers, and 8 lpm for gunners. This information suggests currently used V_A values to predict COHb are likely to seriously underestimate loaders' CO uptake. Based on the data from this study, we propose that future applications of the CFKE utilize a predicted workload of 5 (V_A = 30 lpm) for loaders during combat activity. We lack sufficient information to suggest changes for the other crewmen. In addition, we recommend that future field studies measure tank crewmens' COHb levels before and after firing and that these levels be correlated with ambient CO in the vehicles and with CFKE predictions for COHb.

This study indicates a 3-fold increase in ventilation above baseline is appropriate for estimating toxic inhalation exposure and resulting injury for Live Fire Testing of armored combat vehicles.

This study provides important information in the form of actual field measurements of tank crewmen's ventilatory requirements. We have demonstrated that during a simulated battlefield scenario where crews are firing the tank's main gun at rates averaging 1.3 to 2.1 rounds/min, loaders' maximal ventilatory requirements range from approximately 35-61 lpm with a mean of 47.7 lpm (Table 11). This measurement can be used to evaluate the adequacy of the current NBC system and to guide future design specifications for military armored vehicles. This study documents large differences in ventilatory requirements between loaders and the other crewmen, whose airflow needs were far less under the conditions of our protocol.

In both the M1 and M1A1 tanks, supplied air systems are used for Nuclear, Biologic and Chemical (NBC) protection. Based on a mean measurement of maximal V_E = 47.7 lpm, the present ventilation system is unlikely to meet an exercising individuals' peak inspiratory requirements, which average 2.7 times V_E[30]. Future studies will be required to evaluate peak inspiratory flow requirements for loaders.

One final, important consideration which will require further study deals with the airflow needed to meet physiologic requirements compared to that needed to provide NBC protection. If airflow were diverted to the loader from the other crewmen, their masks might develop significant negative pressure during inspiration, their mask seal might become compromised and they could be exposed to a contaminated environment.

6.0 CONCLUSIONS

a. Loaders in this study were found to have lower aerobic capacity but greater muscular efficiency than control subjects.

b. Loaders in this study did not demonstrate greater upper body exercise performance than controls. Therefore it appears that future laboratory studies can be performed with volunteer soldiers of other military occupational specialties (MOS).

c. Tank crew loaders perceived lower physiologic stress from maximal and submaximal exercise than control subjects.

d. The mock-up exercise protocol performed in our laboratory produced lower levels for maximal heart rate and ventilation than the field study.

e. During a field scenario study, mean maximal V_E for loaders, commanders, gunners and drivers approximated 47, 26, 13 and 12 lpm respectively. Mean ventilation for loaders during rapid firing sequences was 35 lpm. Assuming $V_A = 0.85\ V_E$, loaders working at strenuous exercise will have an average V_A of 30 lpm.

f. Since this protocol was designed to study realistic battlefield workloads primarily for loaders, ventilation data for the other crewmen may not reflect realistic battlefield workloads.

g. This study should not be considered a maximal physiologic challenge for tank crewmen, because other stressors (e.g. MOPP, psychological stress, etc.) are known to increase ventilatory demands.

h. Portable cardiopulmonary monitoring equipment (such as the Oxylog®/Vitalog® apparatus) can be used with limitations to provide field estimates of physiologic requirements.

i. For predicting crew inhalation injury during Live Fire Testing, a 3-fold increase in ventilation above baseline appears to be appropriate.

j. Future studies will be needed (1) to determine maximal ventilatory needs of the other crewmen, (2) to measure peak flow demands and alveolar ventilation of loaders, (3) to determine the effect of additional stressors on ventilatory demands, (4) to define the airflow required to maintain positive mask pressure, thereby preventing exposure to an NBC environment, and (5) to measure tank crewmen's COHb levels for correlation with CFKE predictions.

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Figure 1. M-25 Tanker's Mask with Attached Oxylog® Inspiratory Flowmeter and Exhalation Hose

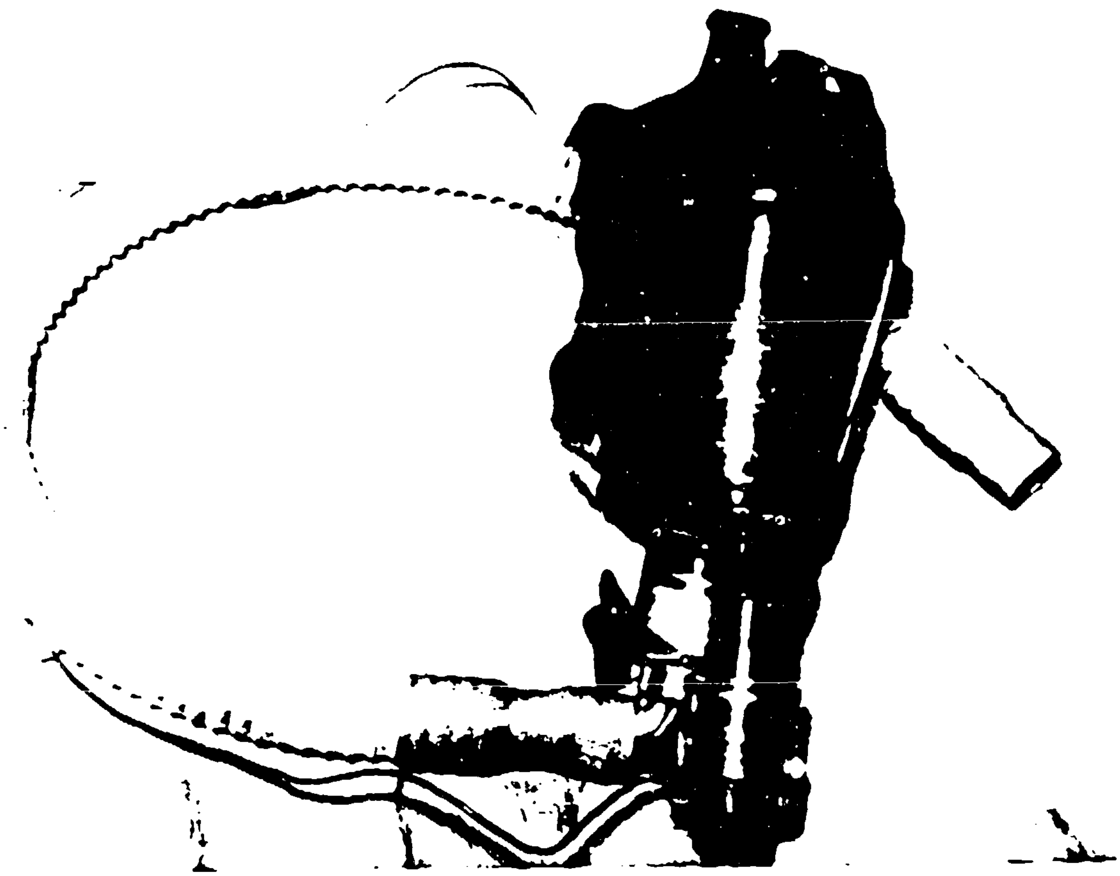


Figure 2. Volunteer Questionnaire and Physical Examination

Name_______________________________________
Participant #______________________________
Age__________________
Sex__________________
Height______________
Weight______________
% Fat________________

Do you have any history of lung diseases?_______If yes, please describe.

Do you have any history of heart diseases?______If yes, please describe.

Are you a cigarette smoker?_______

ENVIRONMENTAL DATA
Ambient temperature__________°C Relative humidity_____________
Barometric pressure__________mm Hg

Figure 3. Instrumented Soldier Performing Mock-up Exercise

Figure 4. Borg Scale for Ratings of Perceived Exertion

6	
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	

Figure 5. Arm Crank Exercise:
Mean Heart Rate vs Time (Workload)

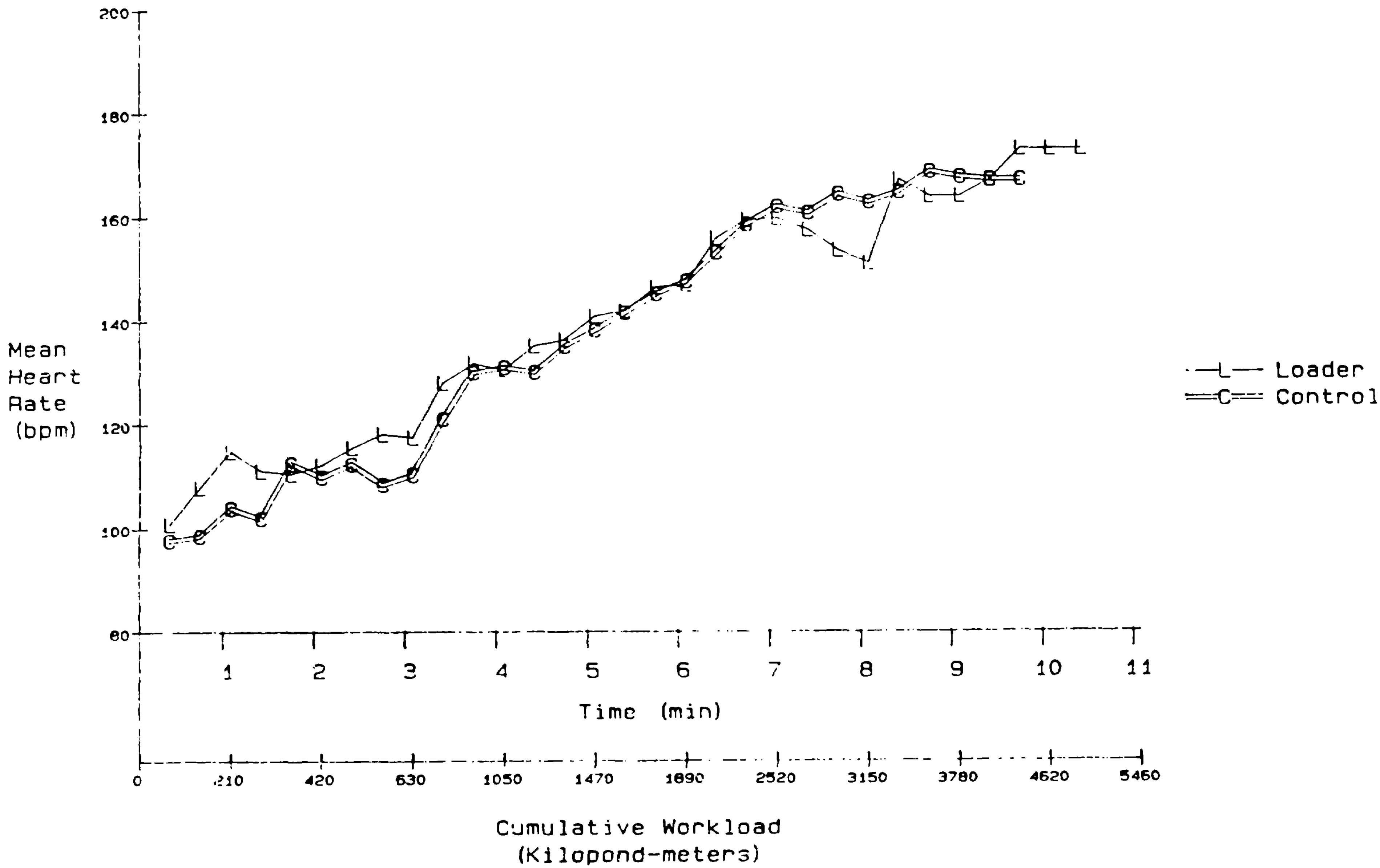


Figure 6. Arm Crank Exercise:
Mean Ventilation vs Time (Workload)

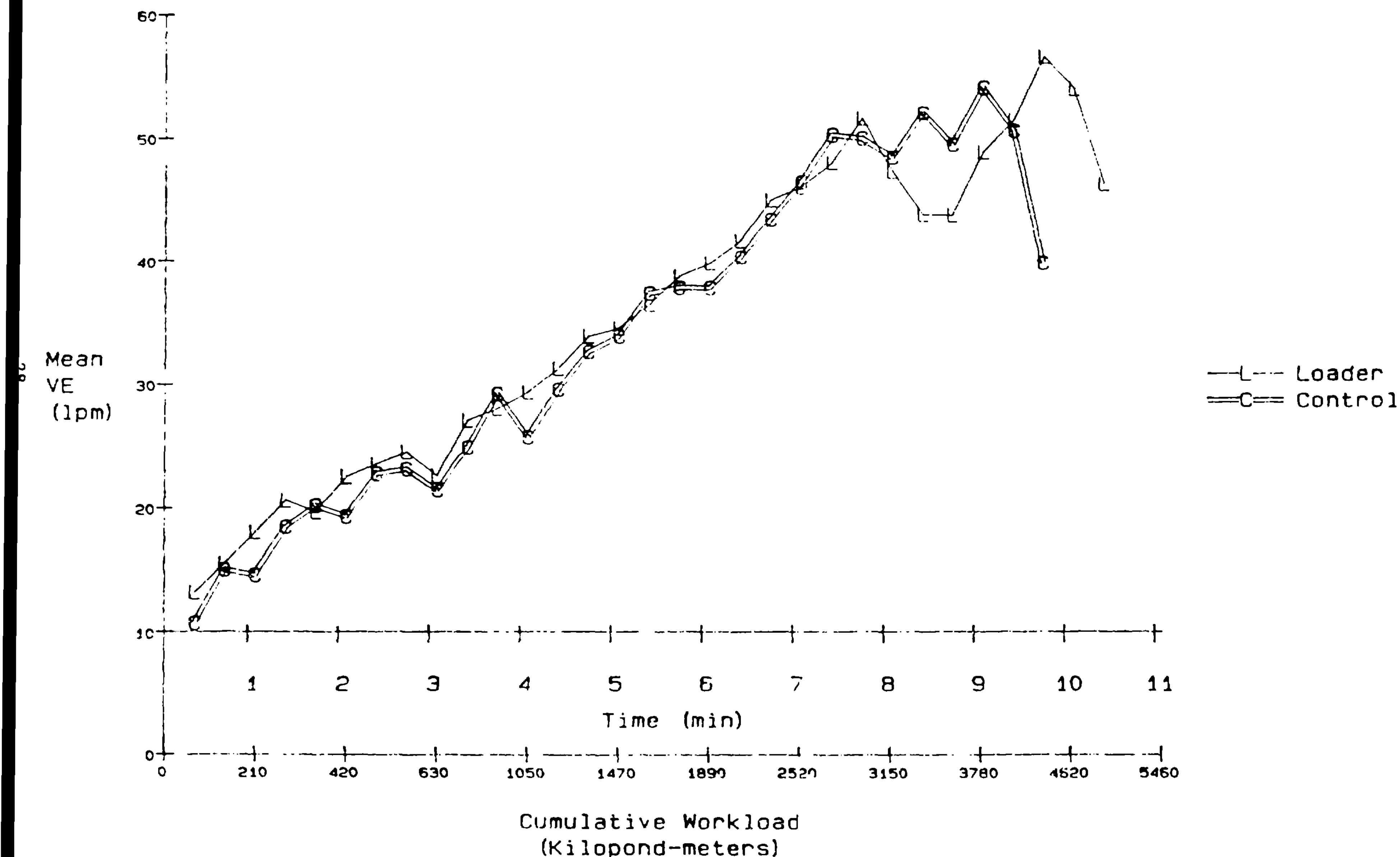


Figure 7. Arm Crank Exercise:
Mean Oxygen Consumption per Kilogram vs Time (Workload)

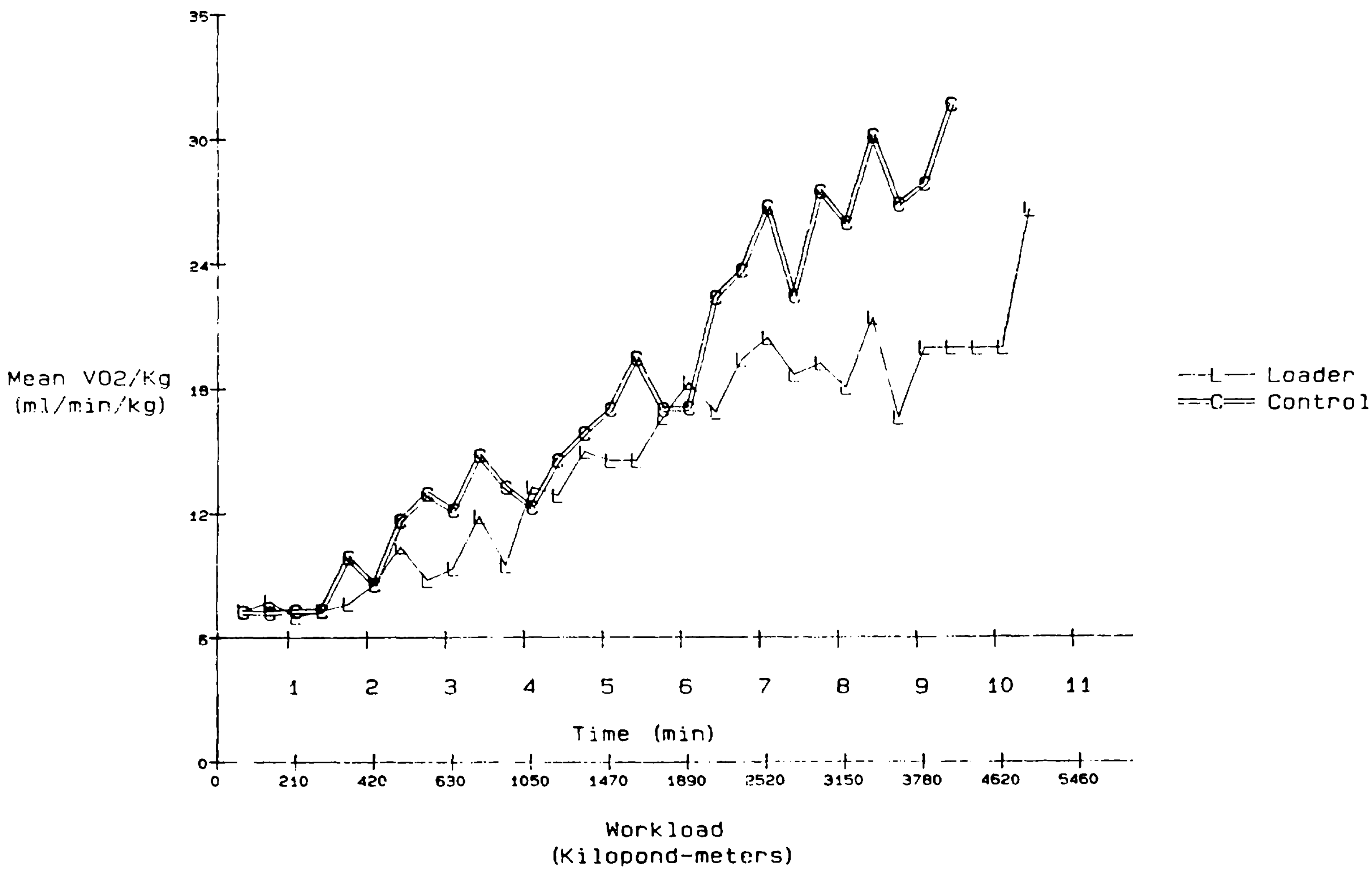


Figure 8. Arm Crank Exercise:
Total Oxygen Consumption per Kilogram vs Time (Workload)

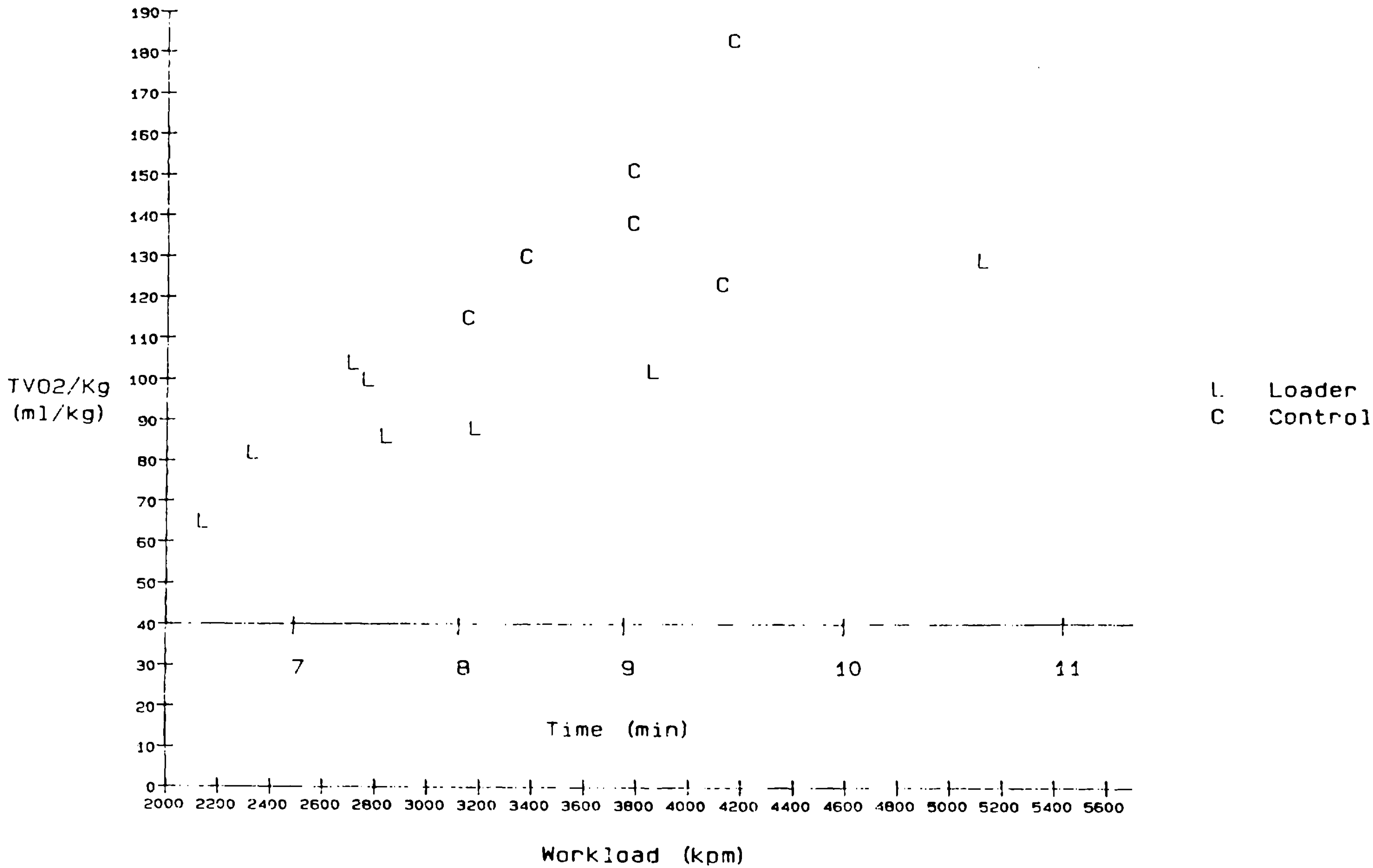


Figure 9. Treadmill Exercise:
Mean Heart Rate vs Time (Workload)

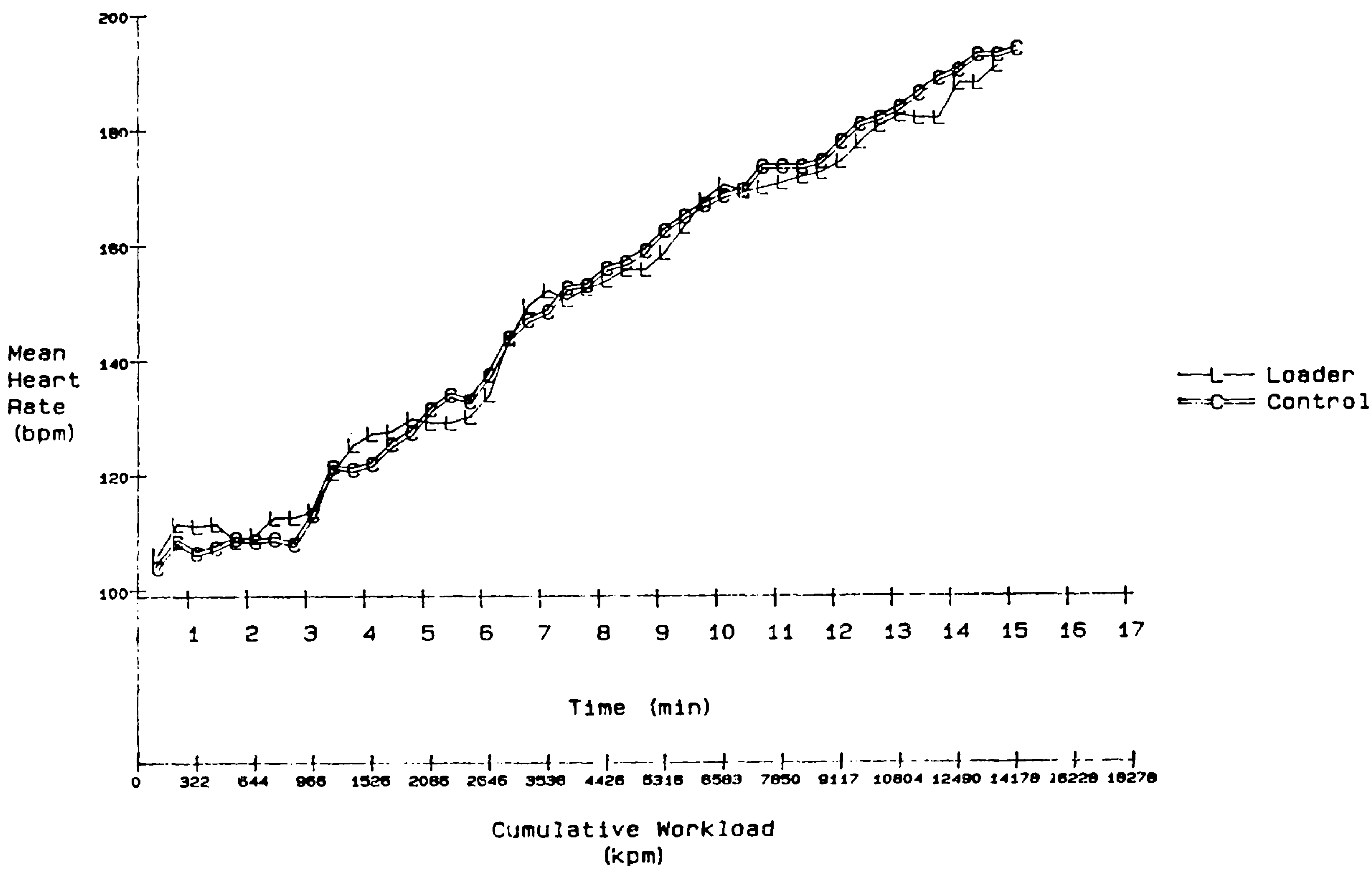


Figure 10. Treadmill Exercise:
Mean Ventilation vs Time (Workload)

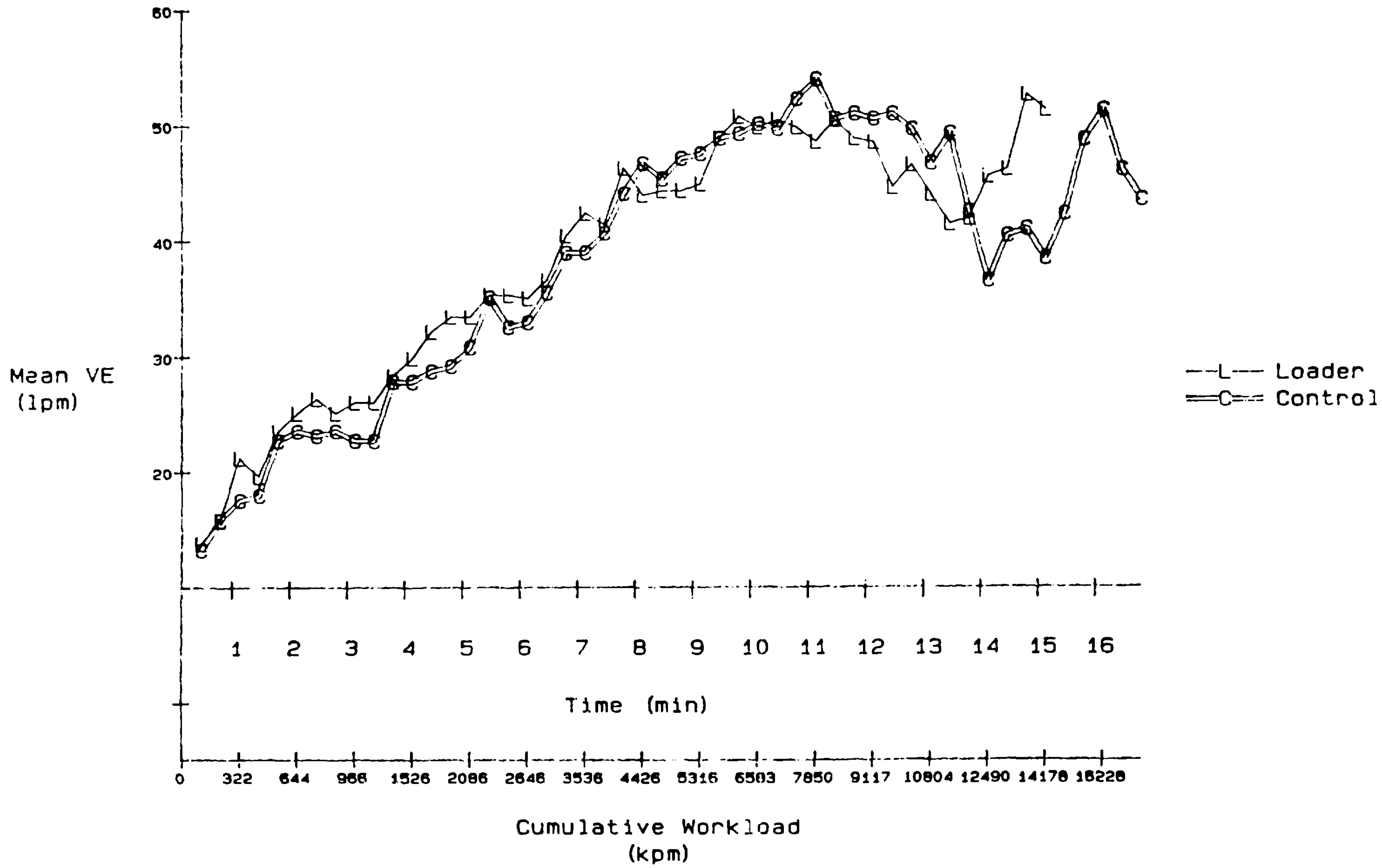


Figure 11. Treadmill Exercise:
Mean Gxyger Consumption per Kilogram vs Time (Workload)

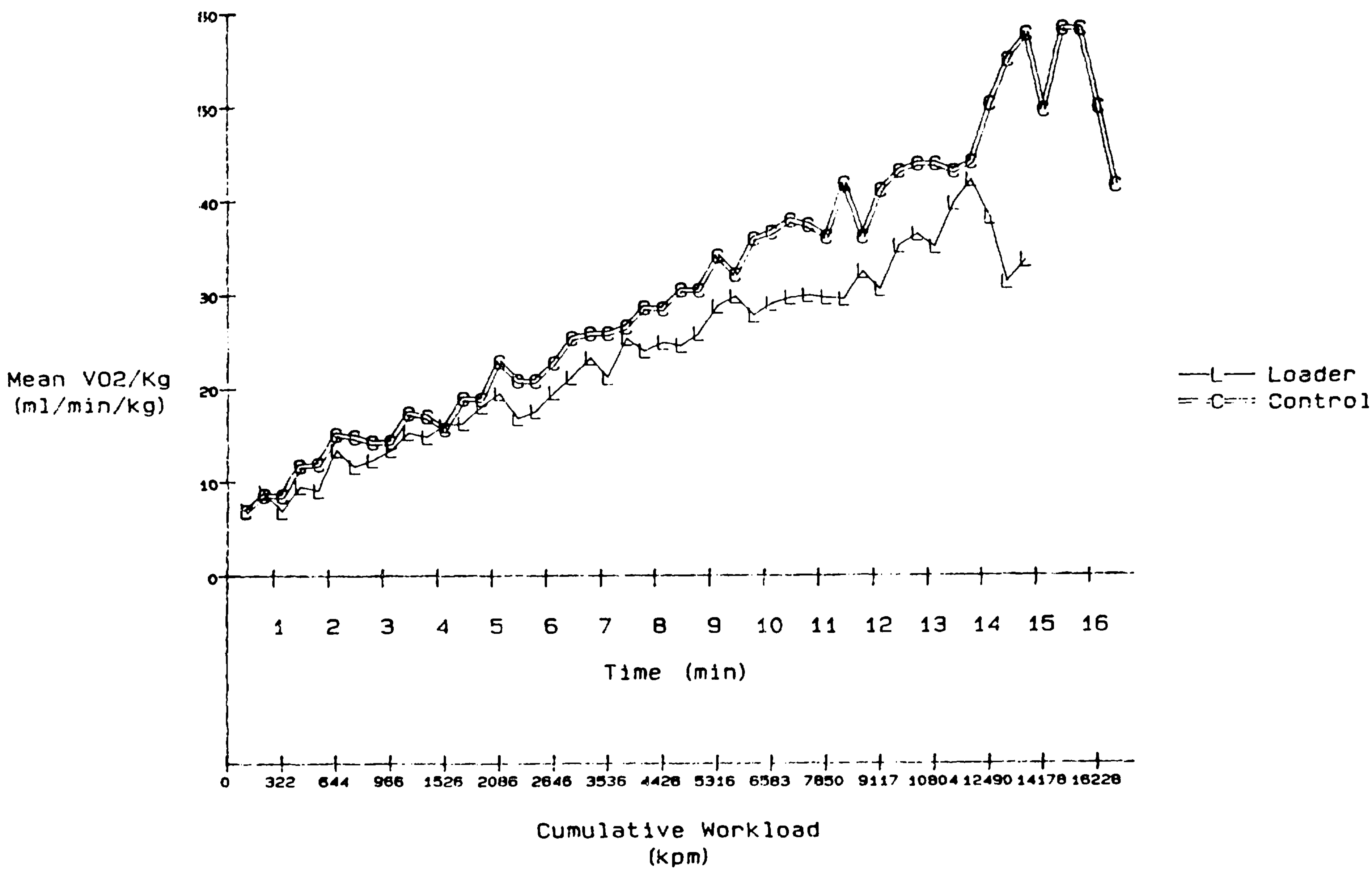


Figure 12. Treadmill Exercise:
Total Oxygen Consumption per Kilogram vs Time (Workload)

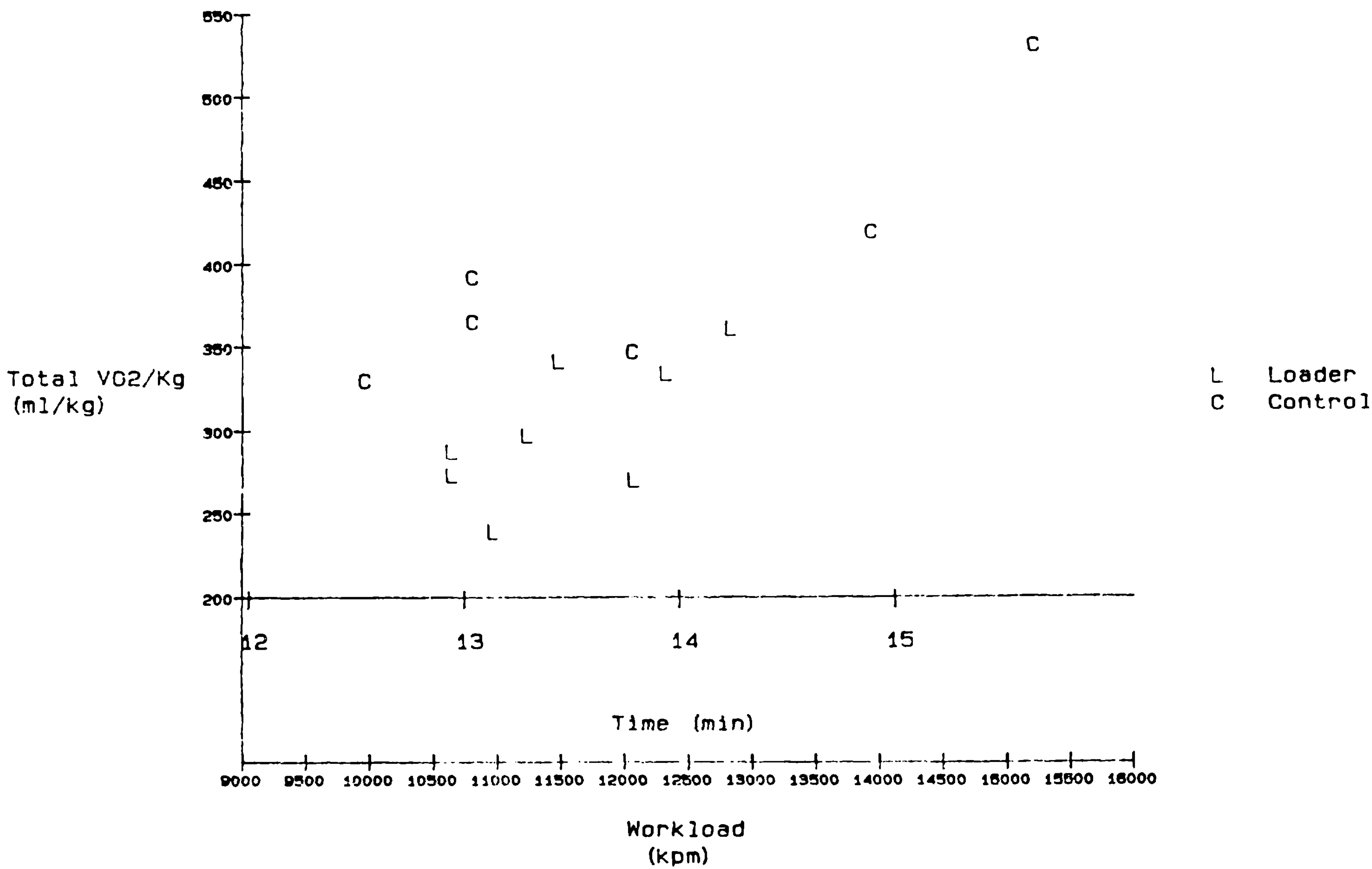


Figure 13. Mock-Up Exercise:
Mean Heart Rate vs Time

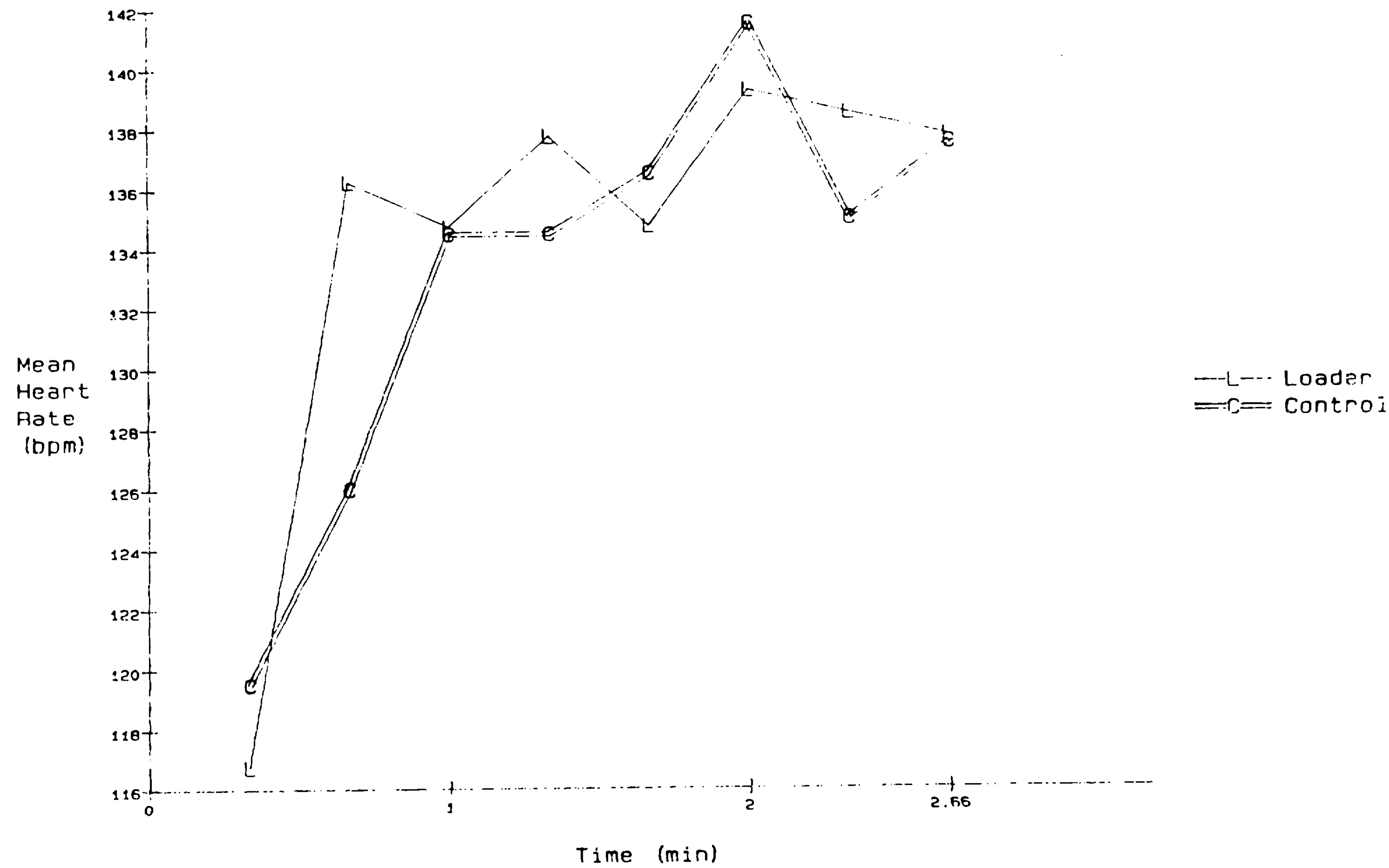


Figure 14. Mock-Up Exercise:
Mean Ventilation vs Time

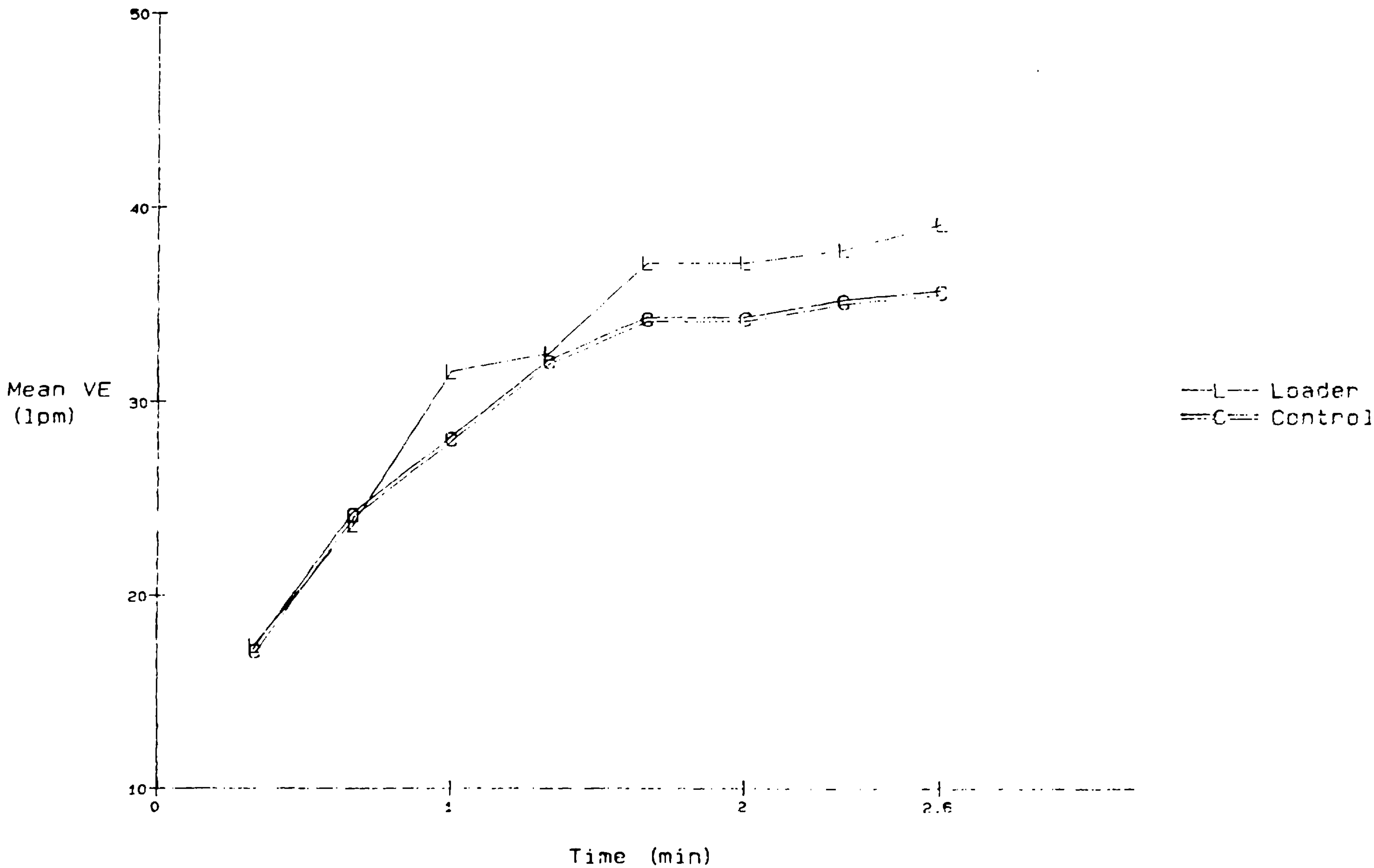


Figure 15. Mock-Up Exercise:
Mean Oxygen Consumption per Minute per Kilogram vs Time

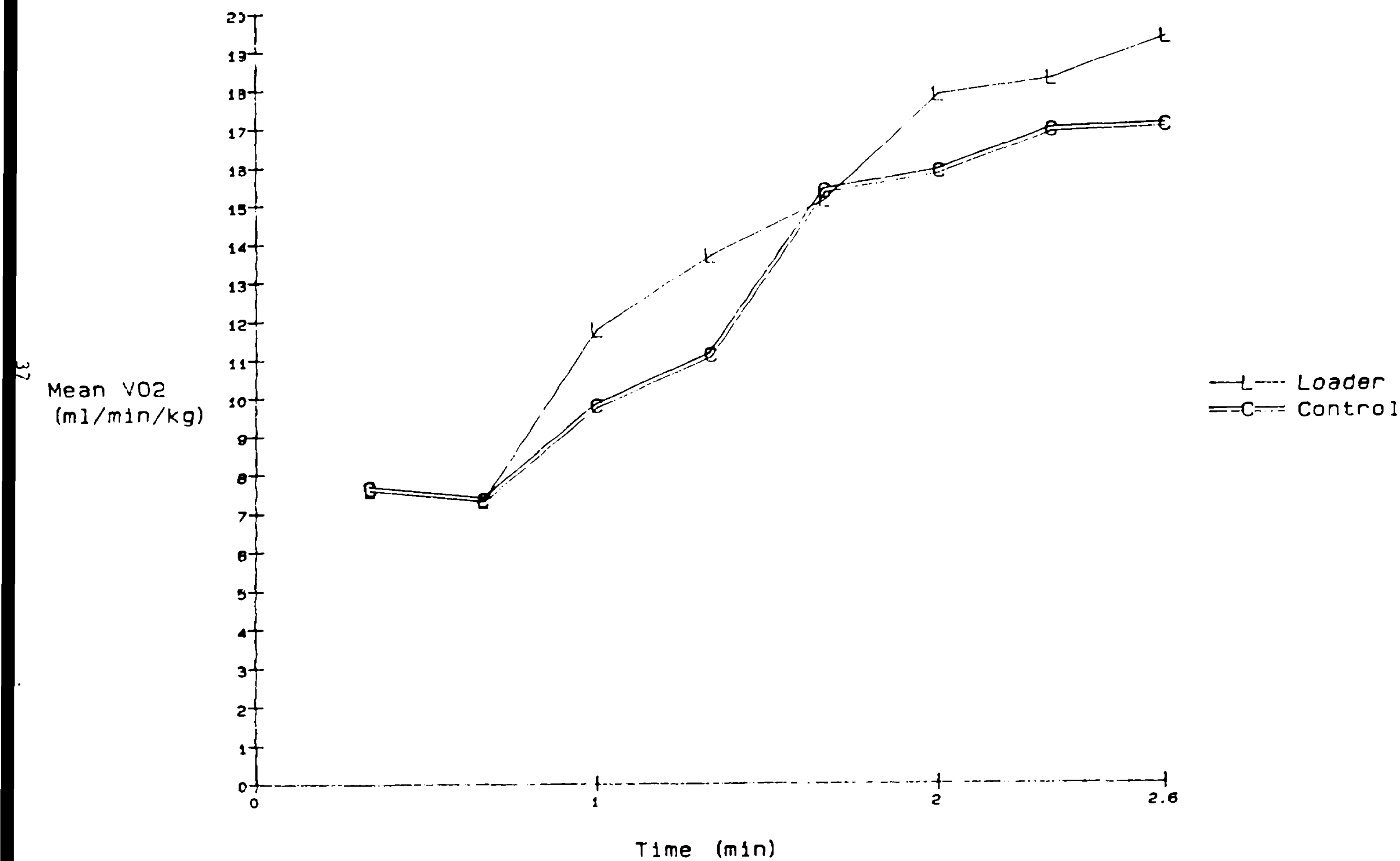
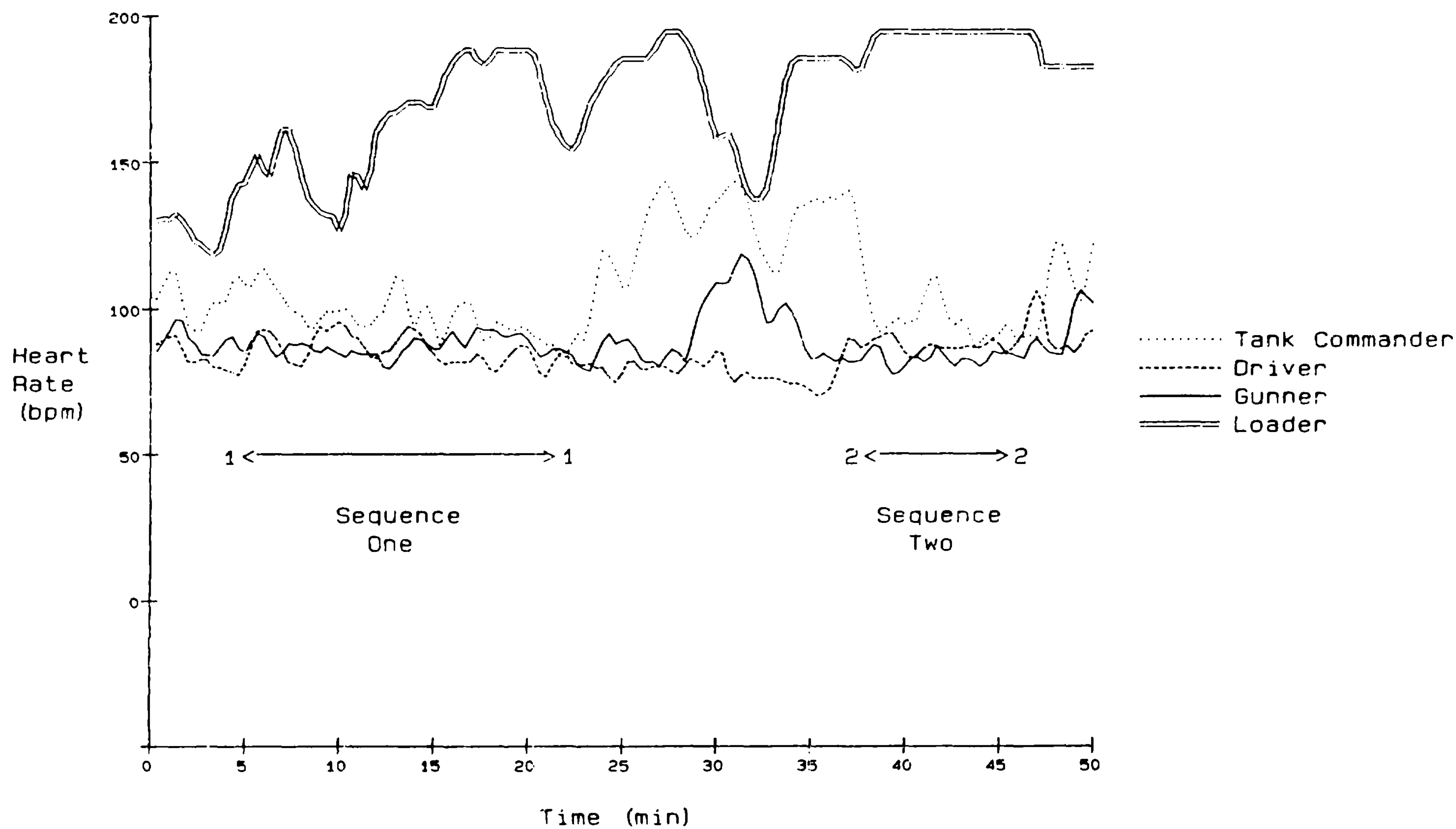
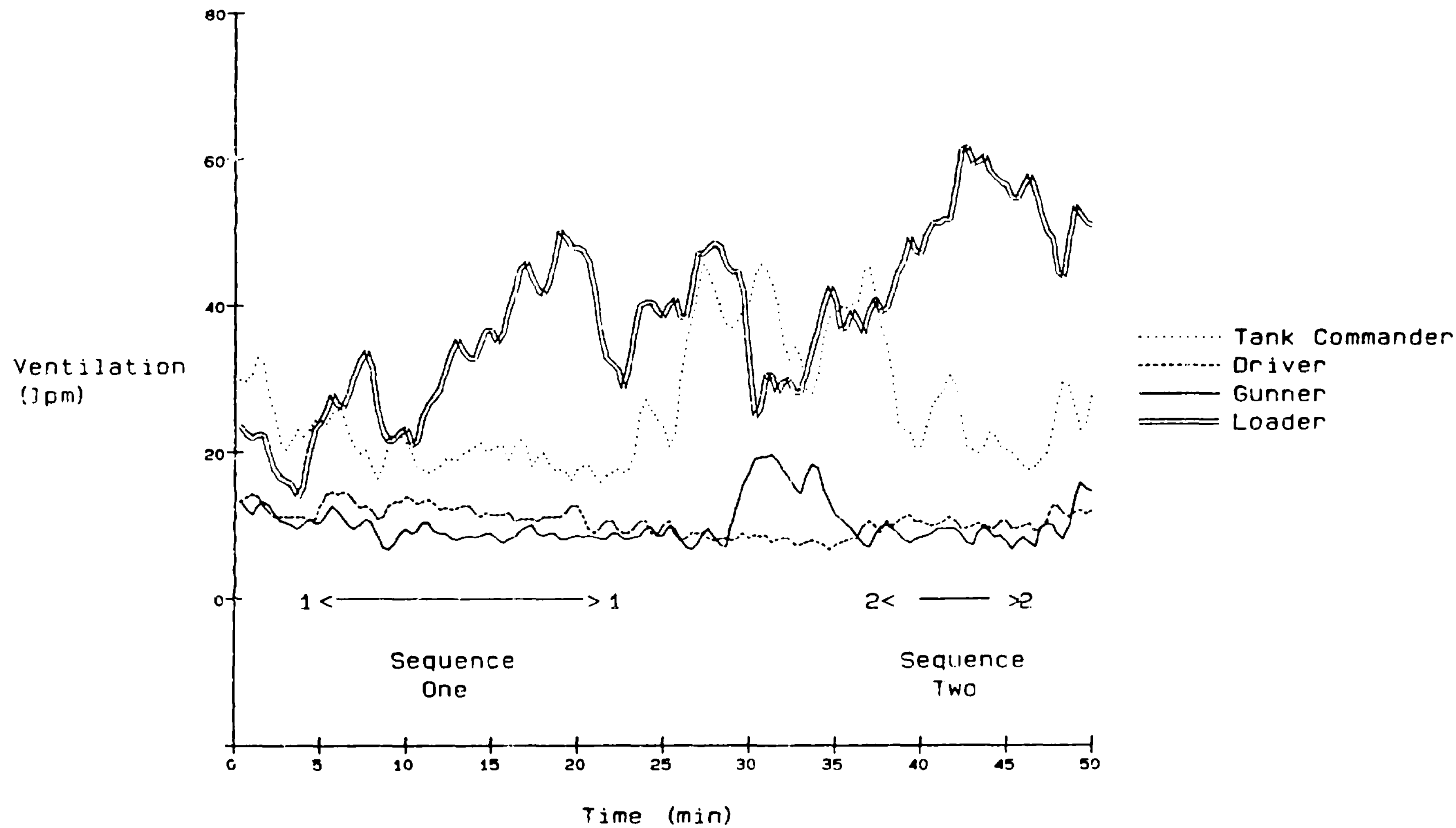


Figure 16. Sequential Measurements of Crew Heart Rates during Tank Firing



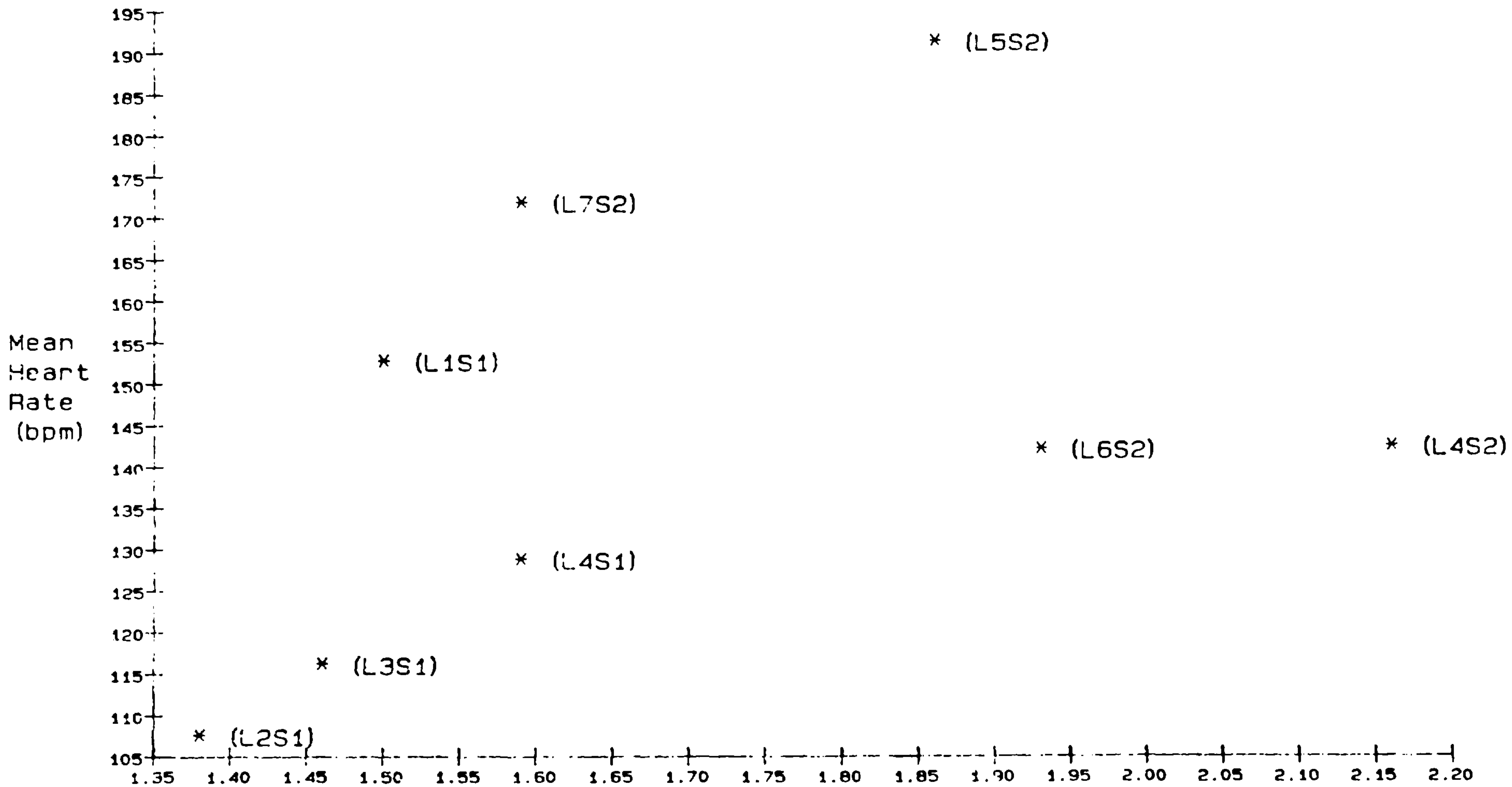
Note: Tank commander assisted with entire redistribution.
Gunner replaced loader for 5 minutes during internal redistribution.

Figure 17. Sequential Measurements of Crew Ventilation during Tank Firing



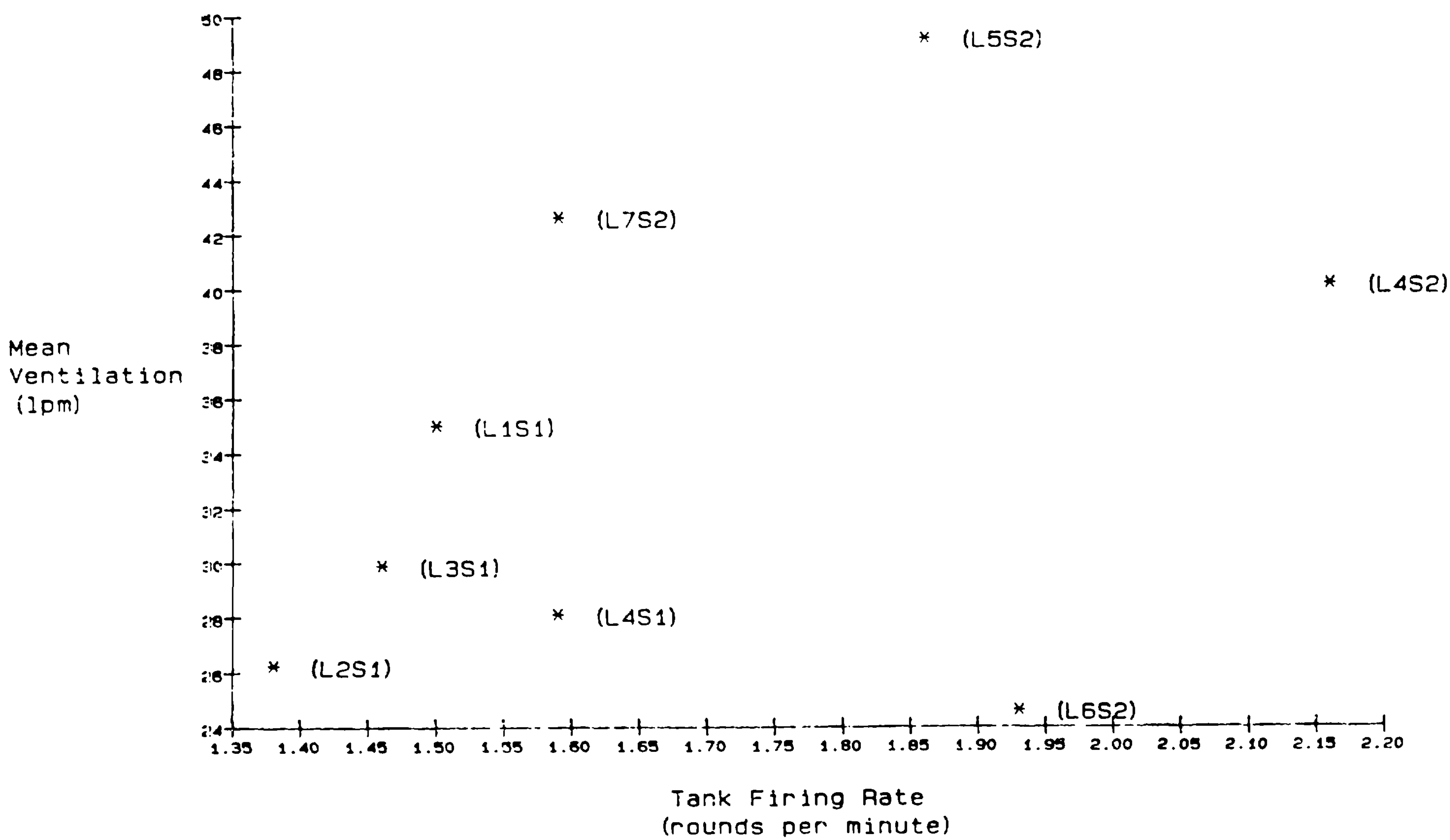
Note: Tank commander assisted with entire redistribution.
Gunner replaced loader for 5 minutes during internal redistribution.

Figure 1B. Firing Sequences:
Mean Heart Rate vs Tank Firing Rate



L - Loader Number
S - Firing Sequence

Figure 19. Firing Sequences:
Mean Ventilation vs Tank Firing Rate



L - Loader Number
S - Sequence Number

Figure 20. Firing Sequences:
Mean Heart Rate By Crew Position

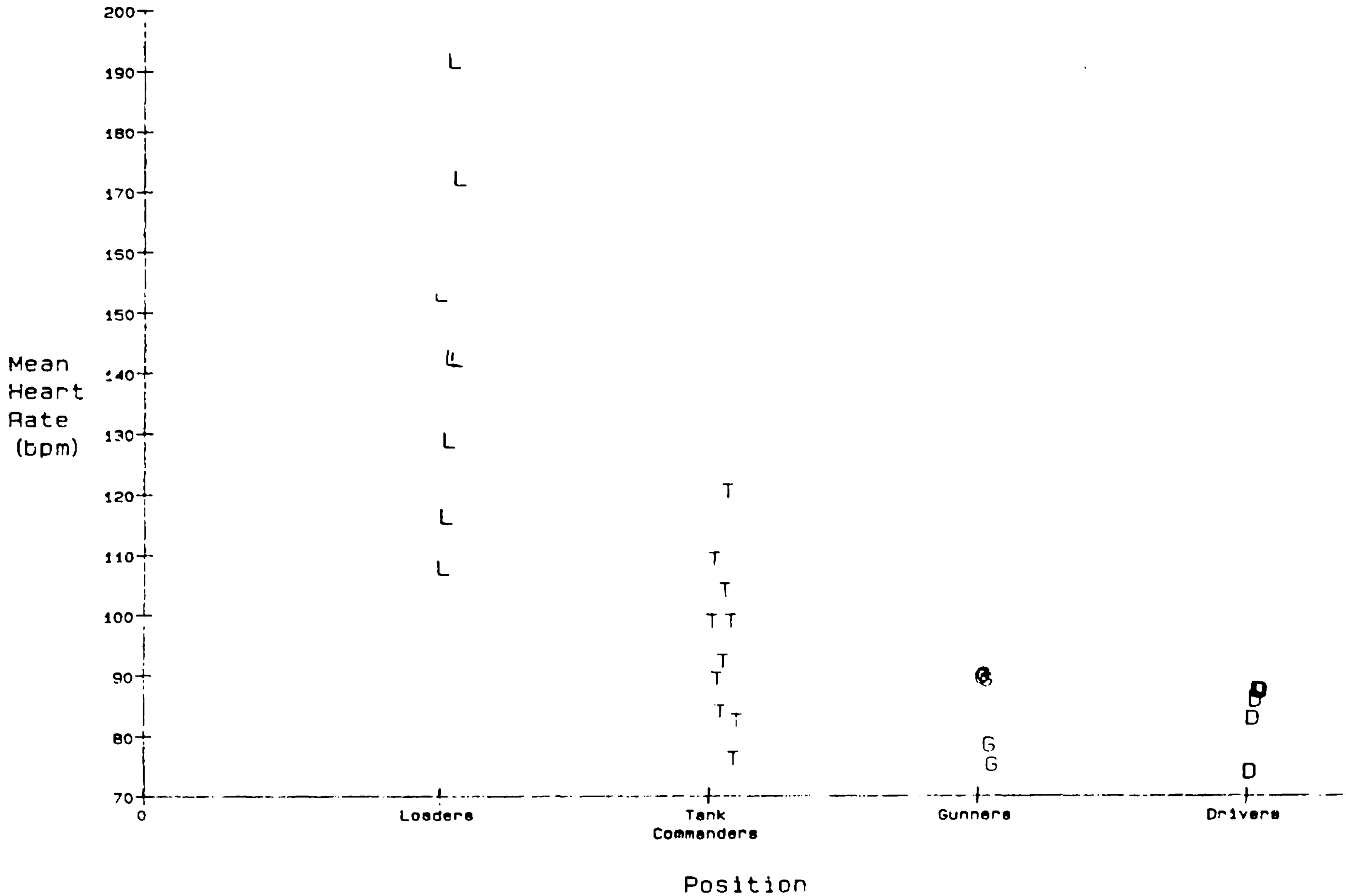


Figure 21. Firing Sequences:
Total Ventilation By Crew Position

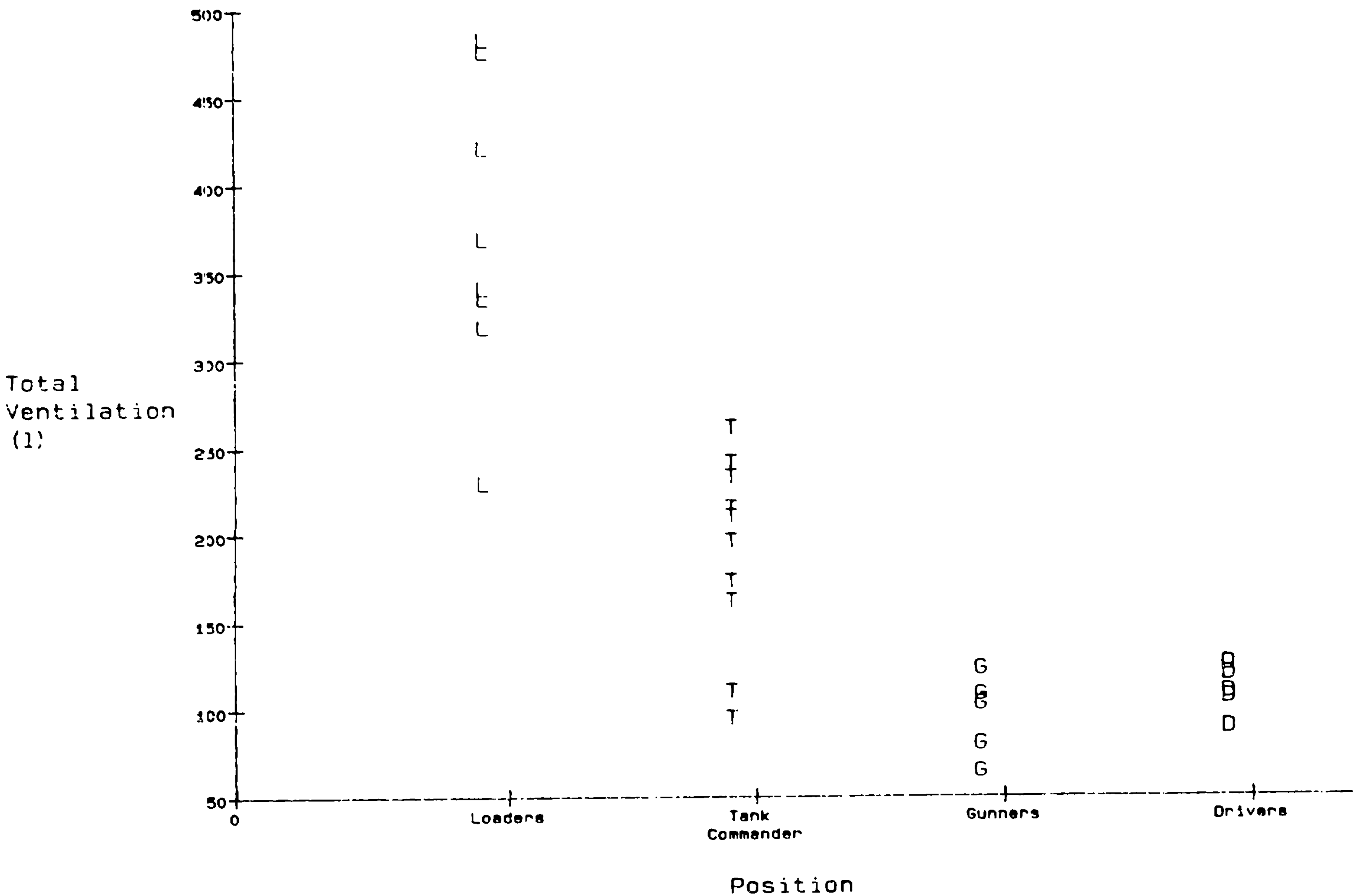


Table 4. Physical Characteristics of Control and Study Subjects

Subject	Age (yr)	Height (cm)	Weight (kg)	%ile Fat	FVC (% Pred)	FEV1 (% Pred)	FEV1% (%)
Controls							
1	23	180	89	45	108	108	84
2	28	180	76	35	145	141	80
3	21	173	80	75	108	100	78
4	19	183	73	50	104	109	87
5	21	183	75	50	118	107	75
6	19	170	72	50	113	111	85
MEAN	21.8	178	77	50.8	116	113	81.5
Loaders							
1	27	173	66	15	121	116	79
2	22	175	93	70	91	85	79
3	21	168	75	70	114	112	84
4	24	168	73	60	97	96	84
5	21	170	72	70	91	81	75
6	20	178	84	70	109	107	83
7	20	170	66	75	97	86	75
8	28	185	98	85	102	100	78
MEAN	22.9	173	78	64.4	103	98	79.6
p-value	NS	NS	NS	NS	NS	NS	NS
Tank Commanders							
1	23	175	64	25			
2	40	183	93	60			
3	31	188	92	60			
4	27	183	75	65			
5	26	188	98	55			
6	31	188	98	65			
7	26	175	72	45			
8	27	180	77	60			
MEAN	28.9	183	84	54.4			
Drivers							
1	26	178	81	40			
2	21	175	80	60			
3	25	175	75	65	(Also drove tank #8)		
4	28	173	86	80			
5	30	170	80	50			
6	22	173	67	30			
7	20	178	77	45			
MEAN	24.6	175	78	52.9			
Gunners							
1	35	178	80	75			
2	27	188	90	45			
3	26	178	64	50			
4	22	173	73	50			
5	30	178	78	50			
6	21	170	68	20			
7	22	185	87	90			
8	28	178	91	85			
MEAN	26.4	178	79	58.1			

Table 5. Arm Crank Protocol: Cardiopulmonary Responses

Subject	HRmax	Maximal	Maximal	Predicted	Predicted	% Predicted	Total	Time	Workload	Workload/	Workload/
		VE	VO2/kg	VO2 max	VO2 max/kg	VO2 max/kg	VO2/kg			TVO2/kg	Wt VO2/kg
	bpm	lpm	ml/min/kg	l/min	ml/min/kg	%	ml/kg	min	kpm	kpm/ml/kg	kpm/ml/kg
C1	173	48.1	23.0	3.8	42.2	54.5	123.0	9.40	4120	33	179
C2	176	58.4	29.3	3.4	45.0	65.1	130.0	8.35	3370	23	115
C3	185	55.8	32.5	3.4	42.3	76.8	151.0	9.00	3780	25	118
C4	152	51.5	28.0	3.6	49.7	56.3	130.0	9.00	3780	27	135
C5	182	54.0	33.1	3.6	48.9	67.7	183.0	9.45	4160	23	126
C6	179	54.2	29.4	3.2	43.9	64.7	115.0	8.00	3150	27	111
MEAN	174.5	53.7	29.1	3.5	45.3	64.2	140.0	8.9	3728.7	27.0	130.3
STD DEV	11.8	3.6	3.6	0.2	3.3	8.1	24.4	0.6	402.0	3.6	25.4
L1	185	52.5	26.8	2.9	44.1	60.8	104.0	7.30	2710	26	101
L2	137	46.6	20.0	3.7	39.9	50.1	88.0	8.05	3180	36	159
L3	164	55.9	19.9	3.1	41.3	48.2	86.0	7.50	2840	33	143
L4	146	40.6	15.3	3.0	40.7	37.6	65.0	6.40	2140	33	140
L5	179	43.9	23.3	3.1	43.1	54.1	100.0	7.40	2770	28	119
L6	173	54.0	22.1	3.7	43.7	50.6	129.0	10.60	5120	40	232
L7	170	52.6	24.0	3.0	45.5	52.7	82.0	6.70	2330	28	97
L8	178	53.2	20.9	4.0	40.8	51.2	102.0	9.10	3860	38	185
MEAN	166.6	49.9	21.5	3.3	42.4	50.7	94.5	7.9	3118.8	32.7	146.9
STD DEV	16.2	5.5	3.4	0.4	2.0	6.5	18.9	1.4	984.0	5.0	45.2
p -value	NS	NS	<0.01	NS	NS	<0.01	<0.01	NS	NS	<0.05	NS

Table 6. Ratings of Relative Perceived Exertion for Phases II and III

Subject	Arm Crank			Treadmill			Mock-up			Field Study		
	M	C	G	M	C	G	M	C	G	M	C	G
Controls												
1	18	18	18	15	15	16	11	12	12			
2	19	16	17	17	17	17	12	12	12			
3	18	17	18	13	17	14	11	10	12			
4	16	13	15	12	18	15	11	12	11			
5	18	15	17	18	18	18	12	13	12			
6	17	19	17	16	18	16	10	12	11			
MEAN	17.7	16.3	17	15.2	17.2	16	11.2	11.8	11.7			
Loaders												
1	17	16	16	13	17	15	9	12	11	11	13	12
2	16	13	15	11	13	13	6	9	8	12	12	15
3	13	15	13	13	13	14	11	10	12			
4	17	15	16	13	17	15	7	7	7			
5	17	14	14	10	17	14	7	12	12			
6	17	11	13	15	15	15	9	7	9	9	9	7
7	15	12	14	17	14	19	7	12	11	13	16	18
8	16	13	13	11	17	14	7	8	7	12	14	14
MEAN	16	13.6	14.3	12.9	15.4	14.9	7.9	9.6	9.6	11.4	12.8	13.2
p-value*	<.05	<.05	<.01	NS	NS	NS	<.01	<.05	<.05			
Tank Commanders**												
1										12	13	13
2										13	17	15
6										15	17	13
7										14	16	14
8										11	12	14
MEAN										13	15	13.8
Drivers**												
2 (assisted with ammunition resupply)								14	17	14		
6										11	7	8
7										7	7	118
MEAN										10.7	10.3	11
Gunners**												
6										13	9	9
7										8	16	11
8										9	9	9
MEAN										10	11.3	9.7

* Statistical analysis only for laboratory exercise protocols

** Field study RPE data recorded only for crewmen completing uninterrupted scenarios

Table 7. Treadmill Protocol: Cardiopulmonary Responses

Subject	HRmax bpm	% Pred HRmax	Maximal VE lpm	Maximal VO2/kg ml/min/kg	Predicted VO2 max l/min	Predicted VO2 max/kg ml/min/kg	% Predicted VO2 max/kg	Total VO2/kg ml/kg	Time min	Workload kpm	Workload/ TVO2/kg kpm/ml/kg	Workload/ M VO2/kg kpm/ml/kg
C1	182	93	55.6	47.2	3.8	42.2	111.8	365	13.00	10800	30	229
C2	179	93	53.1	47.4	3.4	45.0	105.3	330	12.50	9960	30	210
C3	188	95	59.9	44.4	3.4	42.3	105.0	347	13.75	12080	35	272
C4	194	98	54.8	52.1	3.6	49.7	104.8	392	13.00	10800	28	207
C5	191	97	54.8	60.3	3.6	48.9	123.3	419	14.85	13930	33	231
C6	194	98	59.8	55.6	3.2	43.9	126.7	531	15.50	15200	29	273
MEAN	188.0	95.8	56.3	51.2	3.5	45.3	112.8	397.3	13.8	12125.0	30.7	237.0
STD DEV	6.3	2.3	2.3	6.0	0.2	3.3	9.9	72.8	1.2	2045.3	2.8	29.1
L1	194	101	54.8	46.9	2.9	44.1	106.3	341	13.40	11480	34	245
L2	164	84	56.5	37.0	3.7	39.9	92.7	270	13.75	12070	45	326
L3	185	94	57.3	36.7	3.1	41.3	88.9	334	13.90	12320	37	336
L4	185	95	57.3	36.5	3.0	40.7	89.7	273	12.90	10640	39	292
L5	191	97	50.5	39.4	3.1	43.1	91.4	287	12.90	10640	37	270
L6	173	88	53.9	33.1	3.7	43.7	75.7	297	13.25	11230	38	339
L7	191	97	60.7	42.2	3.0	45.5	92.7	361	14.20	12830	36	304
L8	173	89	51.4	29.8	4.0	40.8	73.0	239	13.10	10970	46	368
MEAN	182.0	93.1	55.3	37.7	3.3	42.4	88.8	300.3	13.4	11522.5	38.8	310.0
STD DEV	10.8	5.6	3.4	5.3	0.4	2.0	10.5	41.6	0.5	810.3	4.3	40.3
p -value	NS	NS	NS	0.05	NS	NS	<0.01	0.05	NS	NS	<0.01	<0.01

Table 8. Mock-Up Protocol: Cardiopulmonary Responses

Subject	HRmax	Maximal	Maximal	% Predicted	Total
		VE	VO2/kg	VO2 max/kg	VO2/kg
	bpm	lpm	ml/min/kg	%	ml/kg
C1	152	38.6	17.0	40.3	28.7
C2	125	30.8	14.9	33.1	31.0
C3	146	38.5	18.7	44.2	32.7
C4	146	36.8	15.5	31.2	31.1
C5	152	31.7	18.1	37.0	36.2
C6	143	35.1	17.0	38.7	35.4
MEAN	144.0	35.3	16.9	37.4	32.5
STD DEV	10.0	3.4	1.5	4.8	2.9
L1	170	46.2	24.2	54.9	47.0
L2	131	36.8	18.1	45.4	34.2
L3	146	35.9	16.3	39.5	36.3
L4	155	32.5	12.9	31.7	30.9
L5	158	37.7	23.5	54.5	40.5
L6	131	39.4	20.1	46.0	36.9
L7	149	44.5	22.6	50.1	42.8
L8	122	30.8	11.5	28.2	27.7
MEAN	145.3	38.0	18.7	43.8	37.0
STD DEV	16.2	5.3	4.8	10.0	6.3
p -value	NS	NS	NS	NS	NS

Table 9. Correction Equations for Oxylog/Vitalog Systems

Standard

Oxylog Number	Parameter	Slope of Line	Y-Intercept	Deviation about Regression Line
350	ventilation	0.85214	2.2933	1.39864
350	oxygen consumption	0.92582	0.4005	0.19839
351	ventilation	0.85657	1.8112	1.46806
351	oxygen consumption	0.51239	1.6758	0.47273
356	ventilation	0.62228	5.4340	3.87410
356	oxygen consumption	0.53676	0.8870	0.39586
357	ventilation	0.71960	13.4709	5.27727
357	oxygen consumption	0.56397	1.2676	0.43944
358	ventilation	1.05630	-3.0618	4.14710
358	oxygen consumption	0.85395	0.8263	0.14402
359	ventilation	0.98705	-6.5935	2.88359
359	oxygen consumption	1.18338	0.0106	0.15787

Table 10. Phase III: Temperature and Humidity Corrections

Crew #	Average Temp (°C)	Average Humidity (%)	% Error
1	26.2	58.1	+0.3
2	28.3	52.4	+0.1
3	25.3	61.7	+0.4
4	25.1	60.2	+0.3
5	27.9	58.8	+0.3
6	27.8	54.5	+0.2
7	25.0	70.8	+0.7
8	23.3	79.5	+0.8

CALCULATION OF RELATIVE HUMIDITY

$$\text{Relative Humidity} = \frac{E}{E_{sat}} \times 100$$

where RH = Relative Humidity
E = vapor pressure of water
E_{sat} = saturation vapor pressure

$$E = E_{wet} - [6.44 * 10^4 * P * (T_D - T_w)]$$

where P = Pressure (millibars)
T_D = Dewpoint temperature
T_w = Wet bulb temperature

$$E_{wet} = 6.11 * 10^{\frac{[7.5 * T_w\ (°C)]}{[237.3 + T_w\ (°C)]}}$$

$$E_{sat} = 6.11 * 10^{\frac{[7.5 * T_D\ (°C)]}{[237.3 * T_D\ (°C)]}}$$

From: Duffield, GF, Nastrom, GD. Equations and algorithms for meterological applications in air weather service. Air Weather Service Publication AWS/TR-83/001, Scott Air Force Base, IL, 1983.

Table 11. Maximal and Mean Cardiopulmonary Responses to Live Fire Scenarios

Subject	HRmax	Mean HR	Maximal VE	Mean Ventilation	Maximal VO2/kg
	bpm	bpm	lpm	lpm	ml/min/kg
Loaders					
1	179	153	47.7	35.0	21.2
2	134	108	39.4	28.3	
3	143	116	39.5	29.9	20.5
4	176	142	53.7	40.2	25.5
5	194	182	60.9	49.2	
6	158	142	35.3	24.6	
7	182	172	52.2	42.7	23.3
Mean	167	146	47.0	35.4	22.6
Std Dev	22.1	[illegible]	9.3	9.1	2.3
Tank Commanders					
1	110	99	16.6	14.5	
2	119	109	20.7	18.0	
3	104	90	24.6	19.6	
4	107	92	13.1	11.5	
5	146	104	44.5	27.1	
6	131	121	25.8	22.6	
7	137	99	34.1	19.1	
8	98	83	25.8	16.8	
Mean	119	100	25.7	18.7	
Std Dev	17.3	11.9	9.9	4.8	
Drivers					
2	86	74	12.8	9.7	
3	94	83	10.7	8.9	
5	94	86	12.3	11.1	
6	94	68	10.9	9.6	
7	104	88	13.7	10.6	
Mean	94	84	12.1	10.0	
Std Dev	6.4	5.8	1.3	0.9	
Gunners					
5	113	90	16.3	10.7	
6	98	90	8.8	7.0	
7	98	89	11.7	9.6	
8	94	79	14.9	10.1	
Mean	101	87	12.9	9.4	
Std Dev	8.4	5.4	3.4	1.6	

Table 12: Summary of Loaders' Maximal Cardiopulmonary Performances on Four Exercise Tasks

	MAX HEART RATE (bpm)				MAX VE (lpm)				MAX VO2/Kg (ml/min/kg)			
Loader	AC	Tread	M-U	Field	AC	Tread	M-U	Field	AC	Tread	M-U	Field
1	185	194	170	179	52.5	54.8	46.2	47.7	26.8	46.9	24.2	21.2
2	137	164	131	134	46.6	56.5	36.8	39.4	20.0	37.0	18.1	*
3	164	185	146	143	55.9	57.3	35.9	39.5	19.9	36.7	16.3	20.5
4	149	185	155	176	40.6	57.3	32.5	53.7	15.3	36.5	12.9	25.5
5	179	191	158	134	43.9	50.5	37.7	60.9	23.3	39.4	23.5	*
6	173	173	131	158	54.0	53.9	39.4	35.3	22.1	33.1	20.1	*
7	170	191	149	182	52.6	60.7	44.5	52.2	24.0	42.2	22.8	23.3
8	173	173	122	*	53.2	51.4	30.8	*	20.9	29.2	11.5	*
Mean	167	182	145	167	49.9	55.3	38.0	47.0	21.5	37.6	18.7	22.6
Std Dev	16	11	16	22	5.5	3.4	5.3	9.3	3.4	5.4	4.8	2.3
p-value	NS	NS	0.05		NS	<0.05	<0.05		NS	<0.01	NS	

* data not recorded

APPENDIX 1. **TANK TABLE VI MODIFIED - AEB FAMILIARIZATION COURSE**

TANK CREW: TC _________ L _________ Div_________ Scorer_________

Tank # _____ G _________ D _________ Date/Time ______

TASK	CONDTIONS TARGETS/ SITUATIONS	AMMO	STANDARDS	ENGAGEMENT TIMES 1st	ENGAGEMENT TIMES 2nd	CIRCLE HITS	ENGAEMENTS POINT
1. (TASK VIB-2 MODIFIED)				(Targets - C and M)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down} 2 stationary T-72s, 900-1800m. PRECISON from stationary tank NBC environment {Three man tank crew Gunner blinded by NBC causing TC to fire tank}	3 rds TPDS-T	Must hit stationary tank first within: HIT 1 HIT 2 4 sec. 14 sec. or 6 sec. 14 sec. or 8 sec. 12 sec.			0 1 2	
2. (TASK VIB-3)				(Targets - I and mover A)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down} 1 stationary T-72, 1100-1300m. 1 moving T72, 1000-1300m PRECISON from stationary tank NBC environment	3 rds TPDS-T	Must hit stationary tank first within: HIT 1 HIT 2 4 sec. 18 sec. or 6 sec. 18 sec. or 8 sec. 16 sec.			0 1 2	
3. (TASK VIB-2)				(Targets - Q and X)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down} 2 stationary T-72s, 1400-1800m. PRECISON from stationary tank NBC environment	3 rds TPDS-T	Must hit stationary tank first within: HIT 1 HIT 2 4 sec. 14 sec. or 6 sec. 14 sec. or 8 sec. 12 sec.			0 1 2	
4. (TASK VIB-3)				(Targets - X and mover D)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down} 1 stationary T-72, 1600-1800m. 1 moving T72, 1600-1900m PRECISON from stationary tank NBC environment	3 rds TPDS-T	Must hit stationary tank first within: HIT 1 HIT 2 4 sec. 18 sec. or 6 sec. 18 sec. or 8 sec. 16 sec.			0 1 2	

{} deleted from study scenario

APPENDIX 1. **TANK TABLE VI MODIFIED - AEB FAMILIARIZATION COURSE**

TASK	CONDTIONS TARGETS/ SITUATIONS	AMMO	STANDARDS	ENGAGEMENT TIMES 1st	2nd	CIRCLE HITS	ENGAEMENTS POINT
5. (TASK VIB-2 MODIFIED)				(Targets - I and L and M)			
Engage	{ Move from turret-	3 rds	Must hit stationary			0	
multiple	down to hull-down }	TPDS-T	tank first within:				
targets	3 stationary T-72s,		<u>HIT 1</u> <u>HIT 2</u>			1	
(defense)	1300-1800m.		4 sec. 14 sec.				
	PRECISON from		or			2	
	stationary tank		6 sec. 14 sec.				
	NBC environment		or			3	(add 30% to score in
			8 sec. 12 sec.				table for Task VIB-2)
6. (TASK VIB-3 MODIFIED)				(Targets - movers D and E)			
Engage	{ Move from turret-	3 rds	Must hit stationary			0	
multiple	down to hull-down }	TPDS-T	tank first within:				
targets	2 moving T-72s,		<u>HIT 1</u> <u>HIT 2</u>			1	
(defense)	1600-2000m.		4 sec. 18 sec.				
	PRECISON from		or			2	
	stationary tank		6 sec. 18 sec.				
	NBC environment		or				
			8 sec. 16 sec.				

Pull back off line and redistribute ammunition between the TCs ammunition storage compartment and the Loaders ammunition storage compartment. SWITCH Gunners and Drivers at this time.*

{} deleted from study scenario

* deleted from study scenario after the 4th engagment(task)

APPENDIX 1. **TANK TABLE VI MODIFIED - AEB FAMILIARIZATION COURSE**

TASK	CONDTIONS TARGETS/ SITUATIONS	AMMO	STANDARDS	ENGAGEMENT TIMES 1st	2nd	CIRCLE HITS	ENGAEMENTS POINT
7. (TASK VIIIB-2 MODIFIED)				(Targets - B and N)			
Engage multiple targets (defense)	{Move from turret-down to hull-down} 2 stationary BMPs. 900- 1800m. PRECISON from stationary tank NBC environment {Three man tank crew Gunner blinded by NBC causing TC to fire tank}	3 rds HEAT-T	Must hit BMPs first within: HIT 1 HIT 2 4 sec. 22 sec. or 6 sec. 14 sec. or 8 sec. 10 sec.			0 1 2	
8. (TASK VIIIA-1)				(Targets - J and mover A)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down } 1 stationary BMP, 900-1100m. 1 moving BMP, ~~1000-1300m.~~ { Using GAS, BATTLESIGHT from stationary tank Computer and LRF failure} NBC environment	3 rds HEAT-T	Must hit stationary tank first within: HIT 1 HIT 2 ?? sec. ?? sec. or ?? sec. ?? sec. or ?? sec. ?? sec.			0 1 2	
9. (TASK VIIIB-2)				(TARGETS - K and P)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down } 2 stationary BMPs, 1400-1800m. PRECISON from stationary tank NBC environment	3 rds HEAT-T	Must hit stationary tank first within: HIT 1 HIT 2 4 sec. 22 sec. or 6 sec. 14 sec. or 8 sec. 10 sec.			0 1 2	
10. (TASK VIB-3)				(TARGETS - Q and mover E)			
Engage multiple targets (defense)	{ Move from turret-down to hull-down } 1 stationary BMP, 1300-1600m. ~~1 moving BMP,~~ 1800-2000m PRECISON from stationary tank NBC environment	3 rds HEAT-T	Must hit stationary tank first within: HIT 1 HIT 2 ?? sec. ?? sec. ~~or~~ ?? sec. ?? sec. or ?? sec. ?? sec.			0 1 2	

{} deleted from study scenario

APPENDIX 1. **TANK TABLE VI MODIFIED - AEB FAMILIARIZATION COURSE**

TASK	CONDTIONS TARGETS/ SITUATIONS	AMMO	STANDARDS	ENGAGEMENT TIMES 1st	2nd	CIRCLE HITS	ENGAEMENTS POINT
11. (TASK VIIIB-2 MODIFIED)				**(TARGETS - J and K and N)**			
Engage multiple targets (defense)	{Move from turret-down to hull-down} 3 stationary BMPs, 1100-1600m. PRECISON from stationary tank NBC environment	3 rds HEAT-T	Must hit stationary tank first within:			0	
			HIT 1 HIT 2			1	
			4 sec. 22 sec.				
			or			2	
			6 sec. 14 sec.				
			or			3	(add 30% to score in table forTask VIIIB-2
			8 sec. 10 sec.				
12. (TASK VIB-3 MODIFIED)				**(TARGETS - B and N)**			
Engage multiple targets (defense)	{Move from turret-down to hull-down} 2 moving BMPs, 1600-2000m. PRECISON from stationary tank NBC environment	3 rds HEAT-T	Must hit stationary tank first within:			0	
			HIT 1 HIT 2			1	
			?? sec. ?? sec.				
			or			2	
			?? sec. ?? sec.				
			or				
			?? sec. ?? sec.				

{} deleted from study scenario

APPENDIX 2: FIRING ENGAGEMENT SCORING

Scenario	First Firing Sequence Average Time of Engagement (min:sec)	Second Firing Sequence Average Time of Engagement (min:sec)
1.	1:41	2:20*
2.	1:21	D
3.	1:13	D
4.	1:09	0:51
5.	1:36	0:55
6.	D	1:09
7.	D	0:56
8.	D	D

* Firing sequence was completed but did not meet criteria for either average time of engagement ≤1:00 min) or sequence less than 13.5 min.

D Firing sequence disqualified because of loader injury or equipment malfunction.

Appendix 3. Calibration Data for Oxylogs

Subject	Oxy	Date	Tissot	Tissot	Temp	Bar	FeO2	FeCO2	Tissot	Tissot	Oxylog	Oxylog	Vitalog	Vitalog	Tis/Oxy	Tis/Oxy	Tis/Vit	Tis/Vit	Vit/Oxy	Vit/Oxy	Exercise
Initial	#	1988	start	end		press			vent	O2 cons	vent	O2 cons	vent	O2 cons	O2 cons	vent	2 con	vent	O2 cons	vent	duration
					(Deg C	(Torr)	%	%	l	l	l	l	l	l							min
T	350	Aug-23	10.9	70	21.5	762	0.166	0.043	70.387	3.027	78	3	78	2.40	1.009	0.902	1.261	0.902	0.800	1.000	3
T	350	Aug-23	15.1	89.7	22	762	0.173	0.039	88.648	3.179	103	3.6	103	3.10	0.883	0.861	1.026	0.861	0.861	1.000	3
T	350	Aug-23	8.4	71.3	22	762	0.176	0.034	74.745	2.463	86	2.5	86	2.10	0.985	0.869	1.173	0.869	0.840	1.000	3
S	350	Aug-23	10.3	68	21.5	762	0.180	0.031	68.719	1.988	78	2.2	78	2.00	0.904	0.881	0.994	0.881	0.909	1.000	2
S	350	Aug-23	9.2	71.5	22	762	0.180	0.030	74.032	2.144	80	2.3	84	2.10	0.932	0.925	1.021	0.881	0.913	1.050	2
S	350	Aug-23	10	65.7	22	762	0.174	0.034	66.189	2.320	74	2.5	72	2.20	0.928	0.894	1.054	0.919	0.880	0.973	2
D	350	Aug-23	8.9	49.4	22	762	0.156	0.051	48.127	2.557	56	2.5	55	2.10	1.023	0.859	1.218	0.875	0.840	0.982	3
D	350	Aug-23	6	52.9	22.5	762	0.157	0.051	55.605	2.895	66	3.2	60	2.60	0.905	0.842	1.114	0.927	0.813	0.909	3
D	350	Aug-23	9.8	53.8	22.5	762	0.153	0.053	52.404	2.946	60	3	60	2.70	0.982	0.873	1.091	0.873	0.900	1.000	3
P	350	Sep-16	6.1	18.9	19.5	768	0.173	0.034	15.379	0.555	15	0.6	15	0.00	0.925	1.025		1.025		1.000	2
P	350	Sep-16	13.5	76.2	19.5	768	0.172	0.041	75.334	2.773	90	3.2	87	2.70	0.867	0.837	1.027	0.866	0.844	0.967	2
T	350	Sep-16	17.1	26.5	19.5	768	0.171	0.033	11.294	0.432	12	0.5	12	0.20	0.864	0.941	2.159	0.941	0.400	1.000	2
T	350	Sep-16	12.6	61.9	19.5	768	0.169	0.04	59.234	2.369	66	2.6	67	2.20	0.911	0.897	1.077	0.884	0.846	1.015	2
S	351	Aug-24	6.7	73.4	23	755	0.175	0.037	78.875	2.672	93	3.2	90	2.70	0.835	0.848	0.989	0.876	0.844	0.968	2
S	351	Aug-24	9.5	72.5	23	755	0.174	0.038	74.382	2.593	87	2.7	86	2.40	0.961	0.855	1.081	0.865	0.889	0.989	2
S	351	Aug-25	8.2	74.3	21.5	752	0.173	0.038	78.695	2.826	91	3	88	2.90	0.942	0.865	0.974	0.894	0.967	0.967	2.25
T	351	Aug-24	17.2	84.9	23	755	0.163	0.045	80.058	3.687	90	3.7	91	3.70	0.997	0.890	0.997	0.880	1.000	1.011	3
T	351	Aug-24	10.1	81	22	755	0.168	0.043	84.229	3.445	95	3.5	96	3.30	0.984	0.887	1.044	0.877	0.943	1.011	3
T	351	Aug-25	8.7	83.1	22	752	0.169	0.044	88.377	3.517	102	3.6	102	3.40	0.977	0.866	1.034	0.866	0.944	1.000	3
R	351	Aug-25	9.1	59.5	21	752	0.164	0.043	60.136	2.713	68	2.7	69	1.80	1.005	0.884	1.507	0.872	0.667	1.015	3
R	351	Aug-25	9.1	62.3	22	752	0.162	0.046	63.195	2.974	72	2.9	69	2.30	1.025	0.878	1.293	0.916	0.793	0.958	3
J	351	Sep-12	8.1	62.1	20	765	0.153	0.044	64.739	3.680	75	2.7	72	1.90	1.363	0.863	1.937	0.899	0.704	0.960	3
J	351	Sep-12	9.4	60	20	765	0.161	0.045	60.663	2.923	71	2.6	71	1.90	1.124	0.854	1.538	0.854	0.731	1.000	3
J	351	Sep-12	7.5	64.8	20	765	0.162	0.045	68.575	3.231	80	2.6	77	1.80	1.243	0.857	1.795	0.891	0.692	0.963	3
C	351	Sep-12	9.3	48.4	20	765	0.171	0.036	46.876	1.786	52	1.5	52	1.10	1.191	0.901	1.623	0.901	0.733	1.000	3
C	351	Sep-13	7.9	54.3	21	756	0.171	0.073	55.372	2.011	63	1.9	66	1.30	1.058	0.879	1.058	0.839	1.000	1.048	3
C	351	Sep-13	8.4	59.5	21.5	756	0.171	0.038	60.846	2.312	69	2	68	1.90	1.156	0.882	1.217	0.895	0.950	0.886	3

Appendix 3. Calibration Data for Oxylogs

Subject Initial	Oxy #	Date 1988	Tissot start	Tissot end	Temp (Deg C)	Bar press (Torr)	FeO2 %	FeCO2 %	Tissot vent l	Tissot O2 cons l	Oxylog vent l	Oxylog O2 cons l	Vitalog vent l	Vitalog O2 cons l	Tis/Oxy O2 cons	Tis/Oxy vent	Tis/Vit 2 con	Tis/Vit vent	Vit/Oxy O2 cons	Vit/Oxy vent	Exercise duration min
T	356	Sep-08	6.6	52.5	21	763	0.161	0.044	54.789	2.642	77	3.3	74	2.80	0.801	0.712	0.944	0.740	0.848	0.961	3
T	356	Sep-08	16.5	63.8	21	763	0.164	0.043	56.460	2.547	85	3.5	86	3.30	0.728	0.664	0.772	0.657	0.943	1.012	3
T	356	Sep-08	12.1	72.5	21	763	0.167	0.043	72.098	3.024	105	4.1	105	3.80	0.738	0.687	0.790	0.687	0.927	1.000	3
P	356	Sep-08	7.8	52.7	20	762	0.169	0.037	54.063	2.171	84	3.1	85	2.90	0.700	0.644	0.749	0.636	0.935	1.012	3
P	356	Sep-08	9	51.3	20	762	0.168	0.039	50.707	2.084	84	3.1	82	2.50	0.672	0.604	0.834	0.618	0.806	0.976	3
P	356	Sep-07	10.7	49.6	23	761	0.173	0.036	46.011	1.656	68	2.5	66	1.90	0.663	0.677	0.872	0.697	0.760	0.971	3
D	356	Sep-01	8	58.1	20	764	0.163	0.044	61.260	2.825	97	3.8	95	3.50	0.743	0.632	0.807	0.645	0.921	0.979	3
D	356	Sep-01	10.3	80	20	764	0.166	0.041	59.582	2.568	95	3.7	93	3.30	0.694	0.627	0.778	0.641	0.892	0.979	3
D	356	Sep-01	9	59.3	20	764	0.168	0.04	60.301	2.475	95	3.7	91	3.50	0.669	0.635	0.707	0.663	0.946	0.958	3
SC	356	Aug-31	13.8	79.4	20	755	0.179	0.045	78.859	2.321	121	4.3	117	3.90	0.540	0.652	0.595	0.674	0.907	0.967	3
SC	356	Aug-31	5.3	68.8	20	755	0.167	0.04	76.102	3.204	107	3.7	109	3.30	0.866	0.711	0.971	0.698	0.892	1.019	3
SC	356	Aug-31	8.7	80.4	20	755	0.165	0.041	84.731	3.742	130	4.2	130	3.60	0.891	0.652	1.040	0.652	0.857	1.000	3
S	356	Aug-31	4.3	60.5	20	755	0.178	0.033	67.353	2.223	88	2.8	88	2.60	0.794	0.765	0.855	0.765	0.929	1.000	3
S	356	Aug-31	6.2	61.6	20	755	0.17	0.04	66.395	2.586	91	3.7	90	3.60	0.699	0.730	0.718	0.738	0.973	0.989	3
S	356	Aug-31	7.2	58	20	755	0.173	0.035	60.882	2.195	83	2.5	84	2.00	0.878	0.734	1.097	0.725	0.800	1.012	3
D	357	Sep-01	5.3	72	20	764	0.169	0.041	79.982	3.194	97	3.5	97	3.50	1.098	0.824	0.913	0.824	1.000	1.000	3
D	357	Sep-01	8.6	69.4	20	764	0.169	0.041	71.690	2.864	86	3.2	84	3.10	1.117	0.834	0.924	0.853	0.969	0.977	3
D	357	Sep-01	11.3	68.9	20	764	0.169	0.039	66.655	2.670	81	3	79	2.30	1.124	0.823	1.161	0.844	0.767	0.975	3
SC	357	Aug-31	8.2	62.8	20	755	0.166	0.042	64.237	2.766	76	2.8	74	2.50	0.940	0.845	1.106	0.868	0.862	0.974	3
SC	357	Aug-31	9	81.9	20	755	0.17	0.038	87.368	3.412	104	2.8	103	2.70	0.850	0.840	1.264	0.848	0.931	0.990	3
SC	357	Aug-31	8.8	88	20	755	0.171	0.037	94.918	3.611	114	2.6	110	2.30	0.720	0.833	1.570	0.863	0.865	0.965	3
S	357	Aug-31	1	64.1	20	755	0.172	0.035	75.623	2.805	76	2.4	73	2.20	0.856	0.995	1.275	1.036	0.917	0.961	3
S	357	Aug-31	7.8	64	20	755	0.174	0.034	67.593	2.369	72	2.4	69	2.20	1.013	0.939	1.077	0.980	0.917	0.958	3
S	357	Aug-31	6.2	65.6	20	755	0.175	0.033	71.188	2.423	67	1.9	64	1.50	0.784	1.063	1.616	1.112	0.789	0.955	3
S	357	Sep-15	7.3	62.2	20.5	783	0.173	0.037	65.673	2.361	75	2.5	71	2.20	1.059	0.876	1.073	0.925	0.880	0.947	2
S	357	Sep-15	5.8	71.6	20.5	783	0.177	0.034	78.952	2.520	87	3.2	87	3.00	1.270	0.907	0.840	0.907	0.938	1.000	2
SM	357	Sep-20	11.8	59.7	21.5	757	0.17	0.04	57.038	2.222	68	2.5	69	2.50	1.125	0.839	0.889	0.827	1.000	1.015	3
SM	357	Sep-20	7.7	55.4	22.5	757	0.167	0.043	56.543	2.372	66	2.5	64	1.80	1.054	0.857	1.318	0.883	0.720	0.970	3
SM	357	Sep-21	7.6	54.7	23	757	0.168	0.043	55.702	2.278	67	2.8	66	2.10	1.141	0.831	1.085	0.844	0.808	0.985	3
L	357	Sep-23	23.1	75.3	25	752	0.18	0.035	61.128	1.759	70	1.9	71	1.90	1.080	0.873	0.926	0.861	1.000	1.014	2
L	357	Sep-23	10	53.8	25	752	0.176	0.035	51.406	1.692	59	1.8	58	1.50	1.064	0.871	1.128	0.918	0.833	0.949	2

Appendix 3. Calibration Data for Oxylogs

Subject	Oxy	Date	Tissot	Tissot	Temp	Bar	FeO2	FeCO2	Tissot	Tissot	Oxylog	Oxylog	Vitalog	Vitalog	Tis/Oxy	Tis/Oxy	Tis/Vit	Tis/Vit	Vit/Oxy	Vit/Oxy	Exercise
Initial	#	1988	start	end		press			vent	O2 cons	vent	O2 cons	vent	O2 cons	O2 cons	vent	2 con	vent	O2 cons	vent	duration
					(Deg C	(Torr)	%	%	l	l	l	l	l	l							min
S	358	Sep-20	12.6	68.8	21.5	757	0.177	0.033	66.921	2.139	64	1.9	62	1.40	0.888	1.046	1.528	1.079	0.737	0.969	2
S	358	Sep-20	12.4	69.6	22.5	757	0.173	0.031	67.804	2.032	67	1.8	64	1.60	0.886	1.012	1.270	1.059	0.889	0.955	2
S	358	Sep-20	8.1	70.2	22	757	0.173	0.035	73.780	2.659	74	2.6	74	2.10	0.978	0.997	1.266	0.997	0.806	1.000	3
T	358	Sep-20	8.3	71.2	22	757	0.175	0.037	74.731	2.531	73	2.3	71	1.70	0.909	1.024	1.489	1.053	0.739	0.973	3
T	358	Sep-21	8	56.7	23	757	0.165	0.042	57.594	2.541	59	2.3	58	1.90	0.905	0.978	1.337	0.993	0.826	0.983	4
T	358	Sep-21	9.1	45.6	23	757	0.163	0.042	43.166	1.996	44	1.7	44	1.50	0.852	0.981	1.330	0.981	0.882	1.000	3
SM	358	Sep-21	7.6	55	23	757	0.166	0.045	56.057	2.404	63	2.4	63	1.90	0.998	0.890	1.265	0.890	0.792	1.000	3
SM	358	Sep-22	7.1	50.7	22.5	759	0.165	0.043	51.687	2.277	50	1.9	49	1.80	0.834	1.034	1.265	1.055	0.947	0.980	3
SM	358	Sep-22	5.9	49.9	22.5	759	0.164	0.044	52.161	2.350	55	2.2	56	1.90	0.936	0.948	1.237	0.931	0.864	1.018	3
D	359	Aug-19	13.1	68	22	757	0.162	0.045	65.226	3.073	72	2.8	73	2.50	1.098	0.906	1.229	0.894	0.893	1.014	3
D	359	Aug-19	8.1	56.4	22	757	0.155	0.053	57.385	3.103	64	3	64	2.50	1.034	0.897	1.241	0.897	0.833	1.000	3
D	359	Aug-19	28	76	22	757	0.165	0.044	57.028	2.509	66	2.2	65	2.00	1.141	0.864	1.255	0.877	0.909	0.985	2
T	359	Aug-19	14.8	77.5	22	757	0.169	0.042	74.493	2.972	86	2.8	86	2.50	1.061	0.866	1.189	0.866	0.893	1.000	2
D	359	Aug-22	8.5	49.1	21	762	0.154	0.050	48.460	2.682	57	2.7	57	2.30	0.993	0.850	1.166	0.850	0.852	1.000	3
S	359	Aug-22	15.5	75.5	21	762	0.179	0.030	71.616	2.148	78	1.9	78	1.90	1.131	0.918	1.131	0.942	1.000	0.974	2
S	359	Aug-22	8.7	75.5	22	762	0.179	0.031	79.379	2.378	84	2.2	82	2.00	1.061	0.945	1.189	0.968	0.909	0.976	2
T	359	Aug-22	13	64.4	21	762	0.164	0.043	61.351	2.788	70	3	70	2.60	0.923	0.876	1.065	0.876	0.867	1.000	3
T	359	Aug-22	14.2	77.2	21	762	0.165	0.043	75.197	3.313	84	3.4	85	2.70	0.974	0.895	1.227	0.885	0.794	1.012	3

11.0 LIST OF SYMBOLS AND ABBREVIATIONS

A	Age (years)
ACV	Armored Combat Vehicle
ATPD	Ambient Pressure for Dry Gas at Standard Pressure (mm Hg)
BDUs	Battle Dress Uniforms
bpm	Beats per Minute
BTPS	Body Temperature Pressure Saturated (mm Hg)
C	Cardiopulmonary Fatigue Rating of Relative Perceived Exertion
CFKE	Coburn-Forster-Kane Equation
CO	Carbon Monoxide
COHb	Carboxyhemoglobin
DA	Department of the Army
EKG	Electrocardiogram
f	Respiratory Frequency
$F_E CO_2$	Fractional Concentration of Expired Carbon Dioxide (%)
$F_E O_2$	Fractional Concentration of Expired Oxygen (%)
FEV_1	Forced Expired Volume in One Second (liters)
$F_I O_2$	Fractional Concentration of Inspired Oxygen
FM 17-12-1	Field Manual 17-12-1
FVC	Forced Vital Capacity (liters)
G	Generalized Fatigue Rating of Relative Perceived Exertion
Hb	Hemoglobin
HEAT	High Energy Anti-Tank
HR	Heart Rate
Ht	Height (meters)
kg	Kilogram
kpm	Kilopond-meters (1 kpm = 9.8 Joules)
lpm	Liters per Minute
M	Muscle Fatigue Rating of Relative Perceived Exertion
max	maximum
MIL HDBK 759A	Military Handbook 759A
MIL STD 1742C	Military Standard 1472C
min	Minute
ml	Milliliter
mm Hg	Millimeters of Mercury
MOPP	Mission Oriented Protective Posture
MOS	Military Occupational Specialty
MRDC	Medical Research and Development Command
MVV	Maximal Voluntary Ventilation
NBC	Nuclear, Biologic and Chemical
O_2	Oxygen
% Pred	Percent of Predicted
P_b	Barometric Pressure (mm Hg)
P_{H2O}	Pressure of water vapor (mm Hg)
pO_2	Partial Pressure of Oxygen (mm Hg)
RPE	Rating of Relative Perceived Exertion
scfm	Standard Cubic Feet per Minute
T	Temperature (°C)
TVO_2/kg	Total Oxygen Consumption per Kilogram Body Weight (ml/min)
USAARENBD	U.S. Army Armor and Engineer Board

V_A	Alveolar Ventilation (lpm)
V_D	Dead Space Volume (ml)
V_E	Minute Ventilation (lpm)
VO_2	Volume of Oxygen Consumed (lpm)
V_T	Tidal Volume
WRAIR	Walter Reed Army Institute of Research
Wt	Weight (kg)

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