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PHYSIOLOGICAL STRESSES ASSOCIATED WITH U.S. AIR FORCE GROUNDCREW ACTIVITIES

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This study of the rapid turn-around operation involving F-16 aircraft at Nellis AFB, NV, was performed from August 1983 to April 1984. A total of 38 rapid turn-around exercises were conducted at a site off the regular runway. Each exercise was performed by a team of five men (two crew chiefs, two loaders, and the Jammer driver) and was completed within 18 to 36 min. Members of the team wore either fatigues or CWDE. Regardless of the air temperature and the ensemble worn, the average $\dot{V}O_2$ of the loaders was 40-59% higher than that of the crew chiefs. The average $\dot{V}O_2$ of the Jammer driver was 12% higher than that of the crew chiefs. Changes in HR were similar to those observed for the $\dot{V}O_2$. The total-body SR of individuals wearing the CWDE was consistently higher than when the same individuals wore fatigues. The rate of rise in T_{re} and T_{sk} while performing the task was greater when wearing the CWDE than when wearing fatigues. Resting after completing a turn-around did not reduce heat stress when the CWDE was worn.

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The data suggest that in a hot environment (WBGT about 25°C) tolerance time of each team member was greatly reduced while wearing the CWDE. In conclusion, it should be noted that the data presented in this report are applicable to rapid turn-around exercises using the F-16 in a hot, dry environment. Therefore, when the turn-around task requires significant variations from the exercise described in this report, our conclusions and recommendations may not be applicable.

ACKNOWLEDGMENTS

We are grateful for the support provided by Major General Gene Fischer and for the cooperation of the Commander, 474th Tactical Fighter Wing (TFW), Colonel David F. Tippett. The effort and cooperation of Lieutenant Colonel Gerald Kovach and Senior Master Sergeant Kenneth Duckert were essential for the completion of the project. All volunteer subjects from the 474th TFW were most cooperative, and no words can describe our sincere thanks for their unselfish help and cooperation. We also thank our graduate and undergraduate students who carried out the experimental protocol with precision and dedication.

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INTRODUCTION

Man's performance in stressful environments such as desert heat and aridity is limited by his physiological ability to thermoregulate (Horvath and Yousef, 1981; Yousef, 1980). The stress of heat is more severe when man's work or activity level is increased (Sciaraffa et al. 1980). Even in a hot environment, people who can effectively utilize their evaporative cooling mechanism can maintain thermal equilibrium during relatively hard work. The advent of chemical/biological warfare threats requires the use of vapor barrier garments that deny this important avenue of heat loss.

A key element in the total chemical/biological warfare defense (CWD) strategy must be an understanding of the physiological limits (i.e., thermal tolerance) of the U. S. Air Force (USAF) groundcrew performing its duties in a thermally stressful environment (e.g., desert conditions) while wearing CWD equipment. This information will allow development of scientifically sound policies for increasing efficiency and performance of the groundcrews.

Physiological responses of a USAF groundcrew performing rapid runway-repair exercises have been studied during summer at a southern-tier Air Force base (Myhre, 1982). We conducted a field study of thermal tolerance and energy cost of USAF groundcrews performing the rapid turnaround of fighter aircraft (F-16) at Nellis AFB. Between August 1983 and April 1984, the primary objective of the study was to measure thermal-balance challenges associated with the combined effects of desert heat and work on groundcrew members wearing ensembles during summer and winter seasons.

WORK PROCEDURES

General

The experimental program was initiated with the support and encouragement of Lieutenant General Jack Gregory (then Commander, Nellis AFB). The project support plan was developed in cooperation with Major General Gene Fischer, the present Commander, Nellis AFB. Details of the study program were discussed with Colonel David F. Tippett, Commander, 474th TFW, who assigned Lieutenant Colonels Gerald Kovach and Stanley Drozdz to help plan the logistics of the study.

We are grateful for the full support and cooperation of those individuals and for the volunteer subjects who were regular groundcrew members of the 474th. The spirit of enthusiasm and goodwill of all subjects who participated in the experiments is sincerely appreciated.

Experimental Protocol

From August 1983 to April 1984, 38 rapid turnaround exercises were conducted on the F-16 aircraft; all took place on a site off the regular runway at Nellis AFB. Each exercise was performed by a team of five men (two Crew Chiefs, two Loaders, and the Jammer Driver), with two wearing fatigues and the other three wearing CWD ensembles. Two research assistants recorded a step-by-step description of each task performed by each team member.

The safety measures taken by the USAFSAM scientists were successful in preventing serious heat incidents. (A subject with a rectal temperature of 39.0° C and/or a heart rate exceeding 180 bpm was removed from the experiment.) During the summer each subject completed only one exercise per day; during the winter, from two to four.

Volunteer Subjects

Eighteen subjects were recruited for the experiments; three of these were given assignment changes during the study leaving 15 for whom complete data were obtained. All subjects were a part of the 474th TFW regular groundcrew and were well trained in performing the rapid turn-around exercise. They ranged in age from 19 to 31 years. Their body weight, height, maximum aerobic capacity ($\dot{V}_{O_2}$ max), and percent body fat are summarized in Table 1.

Measurements

Physical Fitness (Aerobic Capacity)

The aerobic capacity (i.e., $\dot{V}_{O_2}$ max) of 15 volunteer subjects was measured by the Balke test using a motor-driven treadmill as described in detail by Dill (1966). The calculation procedure of the test was made using the method described by Consolazio et al. (1951). During the test, heart rate and respiratory frequency were recorded.

Energy Cost of Operational Tasks

The energy cost of all five members assembled for each rapid turn-around was measured as the rate of oxygen consumption ($\dot{V}_{O_2}$, ml/min) during work. This method, successfully followed in our laboratory (Yousef and Dill, 1969), involves collecting expired air in a meteorological balloon as shown in Figures A-1 and A-10 in the Appendix. Expired air then passes through a Parkinson-Cowan low-resistance gas meter to measure its volume and temperature, as shown in Figure A-11. As the expired air volume is measured, samples are taken for measurement of percent O_2 and CO_2; then the volume of O_2 consumed and CO_2 produced are calculated.

Rate of Sweat Loss

Total body sweat rate was calculated from the difference between total body weight before and after each exercise measured on a scale accurate to ± 10 g (shown in Figure A-13) and corrected for insensible loss from the skin, water from the lungs and respiratory passages, and the difference between the weight of CO_2 expired and O_2 consumed. Details of this method have been described by Yousef and Dill (1974).

Heart Rate

Heart rate was monitored continuously using the Medilog, a miniature portable cassette recorder that was developed to continuously record physiological signals (Hill, 1981). The tape recordings were analyzed using an appropriately designed replay system together with a microcomputer. The USAF School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas, processed the tapes.

Rectal and Skin Temperatures

Rectal temperature (T_{re}) and chest skin temperature (T_{sk}) were recorded continuously using the Medilog miniature cassette recorder. (Tapes were processed by USAFSAM.) These recorded values were complemented by periodic (10-min intervals) observations of T_{re} using a Yellow Springs telethermometer as shown in Figure A-12.

Body Fat Content

The underwater weighing method (Dill et al., 1972) was used to measure body density and calculate the percent body fat on 15 of the volunteers.

Meteorological Data

Dry bulb (T_{db}), globe (T_g) and wet bulb (T_{wb}) temperatures were measured as described by Dill et al. (1973).

Statistical Analysis

The t-test was used to determine significance of the data in this study.

TABLE 1. PHYSICAL CHARACTERISTICS OF ALL VOLUNTEER SUBJECTS

Volunteer	Age	Body weight (kg)	Height (cm)	$\dot{V}_{O_2}$ max ml/(kg·min)	Body fat %
SM	22	85.65	181.1	38.5	22.5 B & K 23.0 Siri
GJ-1	24	83.65	182.0	34.0	19.3 B & K 19.5 Siri
PR	19	83.25	170.0	39.4	20.9 B & K 21.2 Siri
TM	20	58.9	169.0	47.1	5.4 B & K 4.5 Siri
FR	30	73.5	181.5	47.8	2.2 B & K 1.1 Siri
CK	21	77.2	181.2	37.7	6.3 B & K 5.5 Siri
CJ	23	89.75	168.0	29.0	32.0 B & K 33.3 Siri
CC	29	89.1	174.8	39.5	18.6 B & K 18.7 Siri
SJ	21	65.95	179.5	46.4	17.8 B & K 17.9 Siri
GJ-2	20	86.2	185.0	48.2	15.3 B & K 15.2 Siri
KC	31	84.6	178.5	36.7	23.7 B & K 24.3 Siri
CV	22	87.8	194.4	44.2	13.1 B & K 12.8 Siri
BK	23	62.65	170.5	39.6	13.4 B & K 13.1 Siri
SE	21	70.65	185.1	44.9	7.7 B & K 7.0 Siri
BR*		64.75			
HM*	22	60.84	180.0		
BD*	20	69.32	175.0		
BT*		75.0	183.0	37.4	21.7 B & K 22.1 Siri

*Incomplete data due to changes in military assignment.

RESULTS AND DISCUSSION

Rapid Turnaround Task

A description of the rapid turnaround exercises as performed on the F-16 at Nellis AFB is presented in two parts. The first is a step-by-step overview of the tasks performed by a five-man loading team; the second, a detailed description of the sequence of tasks performed by each team member: Crew Chief, assistant Crew Chief, Loader 1, Loader 2, and Jammer Driver. The rapid turnaround exercise took from 18 to 36 min. (It should be noted that the procedure followed by the 474th TFW at Nellis AFB may not be identical to that used during operational exercises at other installations, particularly those in Europe and in the Pacific.)

Step-by-Step Overview of the Rapid Turnaround Task

While observing 38 rapid turnaround exercises, we found some variability from operation to operation. The following descriptions are based on one frequently observed sequence of events. The major steps of a turnaround are illustrated in Figures A-1 through A-10. The terms "left" and "right" are used with reference to an observer seated in the cockpit of the aircraft. Station positions are shown in Figure 1.

An exercise begins with the aircraft parked, chocked, and pointed away from the loading location. First the Jammer Driver attaches a set of ground wires to the aircraft; then Loader 1 proceeds from the equipment cart to the missile rail on the right wingtip station (station 9: Figure A-1) and begins a stray-voltage check. While he is doing this, the Crew Chief moves the tow bar to the nose of the aircraft, but does not attach it at this time. The assistant Crew Chief removes the access panel to liquid oxygen (LOX) supplies on the right side of the fuselage, while Loader 2 checks control leads on the right bomb rack (station 7). At this time, Loader 1 moves with his equipment to the left missile rail on the left wingtip (station 1) and conducts stray-

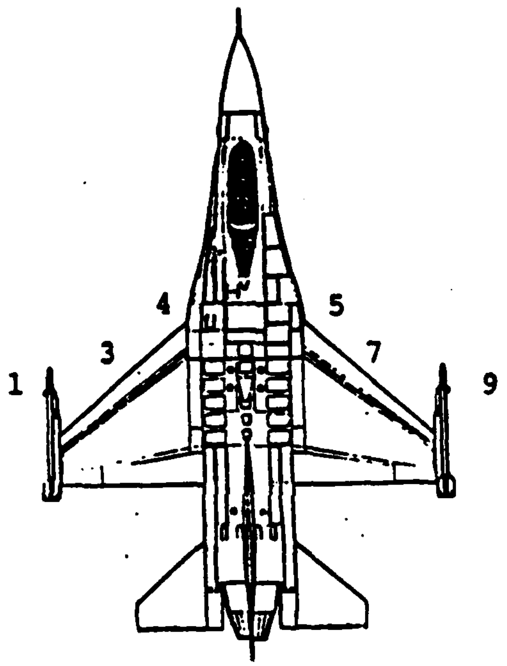

Figure 1. F-16 positions described in step-by-step overview of a rapid turnaround task.

voltage tests there, while Loader 2 checks control leads at the left bomb rack (station 3).

With the stray-voltage test completed, the Crew Chief attaches the tow bar to the nose wheel of the aircraft while the assistant Crew Chief pulls the chocks. The entire team now pushes the aircraft backward into the loading location. When it is in position, the assistant Crew Chief chocks the wheels while the Crew Chief removes the tow bar.

Loader 1 now moves the air compressor to the ammunition loading port on the right forward area of the fuselage (station 5). Loader 2 starts the compressor, and Loaders 1 and 2 together move the ammunition loading system (ALS) cart to a location adjacent to the right forward fuselage (station 5) and begin loading ammunition. Now the Jammer Driver boards the jammer, while the assistant Crew Chief checks and loads the LOX bottle and then closes the access panels to the on-board LOX supply.

At this point, two major operations begin -- bomb loading and refueling. The Jammer Driver starts the engine on the jammer cart. The Crew Chief directs the fuel truck as it backs into place alongside the aircraft, just beyond the right wingtip, and chocks its wheels when it is in position. Meanwhile, the assistant Crew Chief is checking hydrazine stores under the right forward fuselage (station 5). Loader 1 now assists the Jammer Driver in placing one 500-lb bomb on the jammer. They place the first bomb in position at the right bomb mount (station 7) and then mount the other two 500-lb bombs on the right bomb rack. Loader 2 meanwhile, detaches the ALS and removes it from the immediate vicinity of the aircraft. He then deploys the hose from the fuel truck to the rear fuselage area of the aircraft and begins to tighten and secure bombs on the right rack (station 9). The Crew Chief now takes a safety control line to an area in front of the aircraft, and refueling begins.

At about this time, Loader 1 and the Jammer Driver begin to load bombs on the left bomb rack (station 3). When refueling has been completed, the assistant Crew Chief returns the hose to the fuel truck. Loader 1 and the Jammer Driver complete left-side bomb loading operations (station 3), and Loader 2 begins to tighten and secure bombs on the left rack. The Jammer Driver turns off the jammer engine and dismounts.

The Crew Chief now inspects the air intake, and the assistant Crew Chief ascends a ladder to check fuel cells on the aircraft. Loaders 1 and 2 and the Jammer Driver go to an area outboard of the right wingtip and get a missile to load. They lift the missile; proceed to the missile rail on the right wingtip(station 9); and raise, load, and secure the missile on the right missile rail. During the missile-loading procedures, the Crew Chief serves as a safety standby. The Loaders and the Jammer Driver now go to the left wingtip area of the aircraft and load and secure a missile on the left missile rail (station 1). The assistant Crew Chief checks and secures underwing panels on the left side of the aircraft, and the Crew Chief now performs a walk-around inspection. The operation is complete.

Description of the Sequence of Tasks Performed by Each Team Member

Crew Chief. The Crew Chief begins the operation by inspecting the area from the nose of the aircraft. He then moves the tow bar to the aircraft's nose wheel, and from an area in front of the aircraft observes the stray-voltage check and other preliminary procedures. When the stray-voltage check has been completed, he attaches the tow bar to the nose wheel, marshals the entire crew, and with them pushes the aircraft into position for loading (Figure A-1). He then removes the tow bar from the aircraft. This first sequence consumes about 6 min (ranging from 4 to 13 min) of the operation.

From an area in front of the nose of the aircraft, the Crew Chief now observes activities (Figure A-2) until it is time to direct the fuel truck into its loading location, which takes place about 7.5 min (from 5 to 13 min) into the operation. At about 12 min (6 to 16 min) the Crew Chief deploys the fuel hose and grounding cables from the truck to the aircraft and supervises the fueling operation. The fueling is completed at about 18 min (14 to 22 min) into the turnaround, and the Crew Chief proceeds to examine the air intake. He then supervises from an area in front of the nose of the aircraft until tasks are completed, about 25 min (18 to 36 min) into the exercise, and then makes a walk-around inspection of the aircraft.

Assistant Crew Chief. The assistant Crew Chief supervises from the front area of the aircraft until about 3.5 min (0.5 to 6 min) into the operation, at which time he removes access panels from the LOX storage area on the right side of the fuselage. He then removes the chocks from the wheels, helps move the aircraft into its loading position, and rechocks the wheels. Next, he checks and loads LOX, completing this task about 10 min (6 to 22 min) into the operation. At about 11 min (4 to 18.5 min) he proceeds to check the hydrazine stores located in the forward right side of the fuselage (station 5). After the aircraft has been refueled, the assistant Crew Chief returns the fuel hose to the truck and ascends a ladder on the left side of the forward fuselage to check the fuel cells. At about 20 min (12 to 25.5 min) into the operation, he begins to check and secure panels under the right wing. When this has been completed, he stands by in front of the nose of the aircraft until the exercise is completed.

Loader 1. After the aircraft has been grounded, Loader 1 obtains the necessary equipment from the loader cart and begins to test for stray-voltage on the right missile rail (station 9). This is about 3 min (0.5 to 7 min) into the operation; at 5 min (1.5 to 9 min), he is testing for stray-voltage on the left missile rail (station 1). He then walks to the rear of the aircraft and joins the rest of the crew in moving the aircraft into loading position, at about 6 min (4 to

13 min) into the operation. As soon as the aircraft is positioned, Loader 1 moves the air compressor alongside the right forward side of the fuselage to prepare for ammunition loading. He helps move the ALS cart (Figure A-3) to the right forward side of the fuselage (station 5), attaches the ALS to the loading port, and loads ammunition (Figures A-4 and A-5). He now goes to the front of the aircraft and helps the Jammer Driver load bombs (Figure A-6) for the right bomb rack (station 7). In the bomb loading process, Loader 1 aligns the jammer arm with each 500-lb bomb, walks alongside of the bomb as the Jammer moves it to the appropriate rack, aligns the bomb with the appropriate connectors on the rack, and attaches it; he then returns with the Jammer to the bomb storage area immediately outboard of the left wingtip of the aircraft and proceeds with the next bomb (Figure A-7). After the three bombs have been appropriately mated to the right bomb rack (station 7), the procedures are repeated for the left bomb rack (station 3). After the bombs are loaded, Loader 1 goes to the right wingtip and helps in lifting the missile, moving it to the right missile rail (station 9) and attaching it (Figures A-8, A-9, A-10). This process is repeated for the missile on the left wingtip missile rail (station 1). The missile-loading process begins at about 28 min (21 to 35 min) into the operation and is completed in about 4 min.

In our opinion as observers, Loader 1 was by far the most active participant in any of the exercises we observed. He not only participated in all tasks that involved high levels of exertion, but also in a greater number of tasks. He was moving continuously throughout the exercise.

Loader 2. While the stray-voltage checks are being conducted, Loader 2 adjusts connections on the left and right wing bomb racks (stations 3 and 7). He then helps push the plane into its loading position. At about 6 min (4 to 13 min) into the operation, he turns on the air compressor in conjunction with the use of the ALS system for loading ammunition, attaches the ALS syst m to the right fuselage attachment point (station 5) and works with Loader 1 to load ammunition. When ammunition is loaded, he removes the attachment to the aircraft fuselage, turns off the air compressor, and returns the ALS system to an area outboard of the right wing of the aircraft. The ammunition-loading sequence is completed and the ALS is removed at about 14 min (8.5 to 18.5 min) into the operation. Loader 2 then helps tighten the bomb attachments on the right- and left-wing bomb racks (stations 7 and 3 in that order). At about 28 min (21 to 35 min) into the operation, he moves to the area outboard of the right wingtip missile rail and assists in lifting the missile from its cradle, moving it to the right wingtip missile rail (station 9), lifting the missile into place, and holding it there until it is locked and secure. This missile-loading operation is repeated on the left wingtip missile rail, and the missile-loading operation is ended.

Jammer Driver. About 2 min into the turnaround operation, the Jammer Driver attaches ground wires to the aircraft. He then helps push the aircraft into its loading position. This aircraft movement is completed at about 6 min (4 to 13 min) into the operation. The Jammer Driver then boards the jammer and starts the engine. For the next 10 min, the Jammer Driver drives the jammer back and forth from the bomb storage area just outboard of the left wingtip to each of the bomb racks, left and right, until three 500-lb bombs have been loaded on each of the racks. At no time during this loading operation does the Jammer Driver get off the jammer or stop its engine; he is, therefore, seated for this entire period. This loading operation is completed at about 25 min (17 to 33 min) into the overall turnaround operation. At about 28 min (21 to 35 min) into the turnaround, the Jammer Driver assists in lifting a missile from its cradle, moving it to the right wingtip missile rail, lifting it to the rail, and holding it there until it is locked and secured in position (station 9). This procedure is then repeated on the left wingtip missile rail (station 1). This missile-loading operation is completed at about 25 min (18 to 36 min) into the turnaround.

Meteorological Data

The averages and ranges of db, wb, and g temperatures recorded during the experimental period are summarized in Table 2. The environmental heat load was expressed in terms of the wet bulb globe temperature (WBGT) index. The WBGT was calculated as the index for thermal stress using the equation

$$WBGT = 0.7\ (T_{wb}) + 0.2\ (T_g) + 0.1\ (T_{db})$$

During the summer season (August-September 1983) the WBGT ranged between 21.1° and 32.2° C. For January-April 1984, the WBGT ranged from 4.3° to 18.4° C.

Aerobic Capacity and Percent Body Fat of Volunteer Subjects

Fifteen volunteers were measured for aerobic capacity and percent body fat. The maximum rate of O_2 consumption ($\dot{V}_{O_2}$ max) expressed in ml/(kg·min) of these subjects was summarized in Table 2. The range of $\dot{V}_{O_2}$ max was between 29.0 and 48.2 ml(kg·min). Only one subject had a $\dot{V}_{O_2}$ max less than 30 ml/(kg·min); eight had values between 30 and 40 and six had values between 40 and 50 ml(kg·min).

In the subject who had the lowest $\dot{V}_{O_2}$ max, the percent body fat was above 30%. Ten subjects had a body fat of 20% or less, and five had values above 20%. Volunteers with a body fat of 20% or less had an average $\dot{V}_{O_2}$ max of 36.2 ml/(kg·min). The data suggest that only 10 out of the 15 volunteers were in reasonably good physical condition.

Energy Costs of Performing the Rapid Turnaround

The rapid turnaround task on an F-16 was completed in 18 to 36 min. The $\dot{V}_{O_2}$ was measured on each of the five members of each team performing

TABLE 2. METEOROLOGICAL DATA AS MEASURED DURING THE EXPERIMENTAL PERIOD

Month		T_{db}, °C	T_{wb}, °C	T_g, °C	WBGT, °C
1. Aug-Sept 1983	($\bar{X}$)	35.0	21.0	44.3	26.5
	(SD)	±6.8	±1.4	±5.5	±3.2
	(min-max)	24.1-46.0	19-22.8	35-50.1	21.1-32.2
2. Jan-Feb 1984	($\bar{X}$)	9.4	4.3	31.5	10.3
	(SD)	±3.6	±1.6	±6.3	±4.9
	(min-max)	2.8-13.8	1.9-7.6	10.0-39.0	4.32-18.42
3. Mar-Apr 1984	($\bar{X}$)	19.0	8.0	33.7	14.3
	(SD)	±6.4	±2.1	±4.5	±2.7
	(min-max)	8.0-29.9	3.6-11.3	26.0-41.0	8.8-18.3

T_g = globe temp; T_{wb} = wet bulb temp; T_{db} = dry bulb temp

WBGT = wet-bulb globe temperature

the turnaround task; exhaled air was collected for every 3-5 min throughout the task. Examples of the changes in $\dot{V}_{O_2}$ during a turnaround operation for Loaders, Jammer Driver, and Crew Chiefs while wearing the CWD ensemble or fatigues are shown in Figures 2-4. After the first 5 min of the task, $\dot{V}_{O_2}$ of the Loaders (Figure 2) remained at a high level; however, the $\dot{V}_{O_2}$ of the Crew Chiefs (Figure 3) and Jammer Drivers (Figure 4) generally increased to a high level in the first 10 min and then decreased for the remaining period of the task. This pattern of changes in $\dot{V}_{O_2}$ was similar in summer and in winter.

The average $\dot{V}_{O_2}$ of Loaders, Jammer Drivers, and Crew Chiefs under different environmental temperatures is summarized in Tables 3-5. Air temperature from 3 to 46° C had no significant effect on average $\dot{V}_{O_2}$; also the outfit worn, a CWD ensemble or fatigues, had little effect on the average $\dot{V}_{O_2}$ of an individual (Tables 3-5). Regardless of air temperature and the ensemble worn, the average $\dot{V}_{O_2}$ of Loaders 1 and 2 was consistently 40% to 59% higher ($P<.05$), respectively, than of the Crew Chiefs. The average $\dot{V}_{O_2}$ of the Jammer Drivers was about 12% higher than of the Crew Chiefs, but the difference was not statistically significant.

Sweat Rate

Total-body sweat rate (SR) as expressed in terms of $g/(m^2 \cdot min)$ is summarized for the Loaders, Jammer Drivers, and Crew Chiefs in Tables 3, 4, and 5. Under all experimental conditions Loaders 1 and 2 had higher SR ($P<.05$) than did the Jammer Drivers and Crew Chiefs. The high SR of the Loaders is related to the high energy cost of their work as compared to the other team members.

The SR of individuals wearing the CWD ensemble was consistently higher than when the same individuals wore fatigues. This is probably related to the fact that the sweat produced while wearing the CWD did not evaporate and the wetness of the skin resulted in increased skin temperatures, which in turn may have contributed to the increased SR.

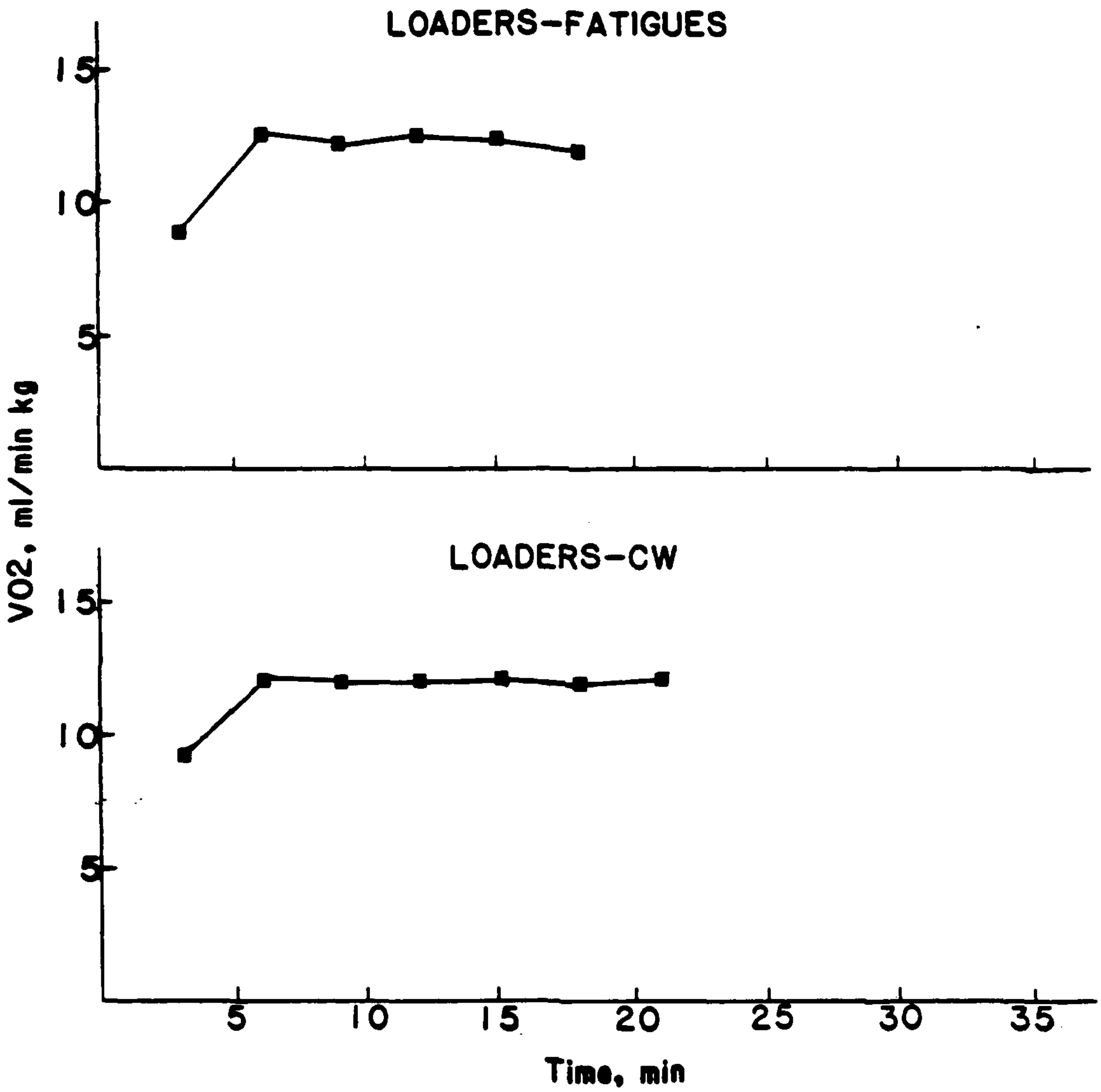

Figure 2. Changes in $\dot{V}_{O_2}$ of Loaders while wearing fatigues or CWD ensembles. Each point represents the average of two subjects during one exercise at a $T_{db} = 41.5°$ C.

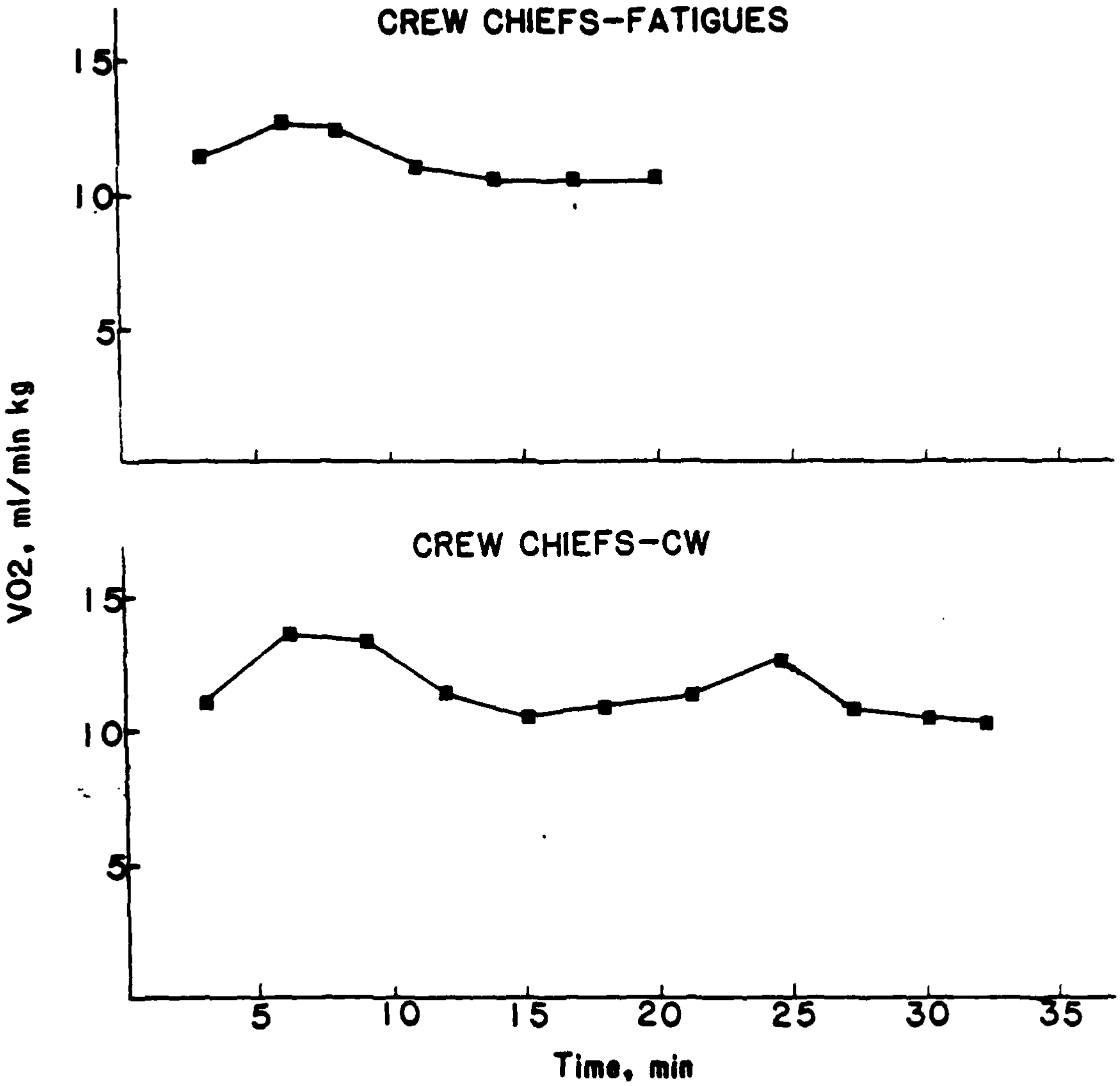

Figure 3. Changes in $\dot{V}_{O_2}$ of Crew Chiefs while wearing fatigues or CWD ensemble. Each point represents one subject during one exercise at a T_{db} = 42.8° C.

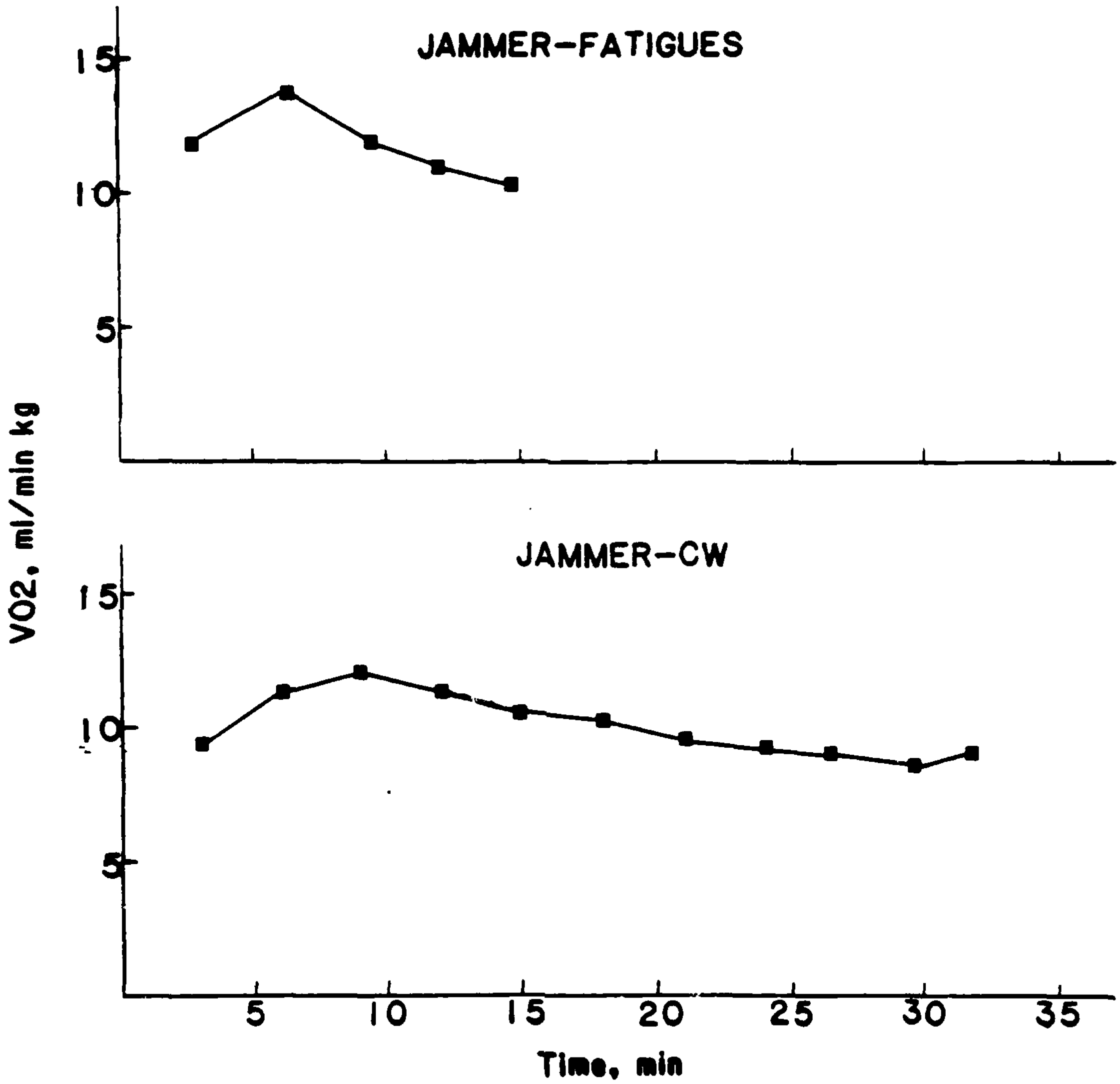

Figure 4. Changes in $\dot{V}_{O_2}$ of Jammer Drivers during a rapid turnaround exercise while wearing fatigues vs. CWD ensemble. Each point represents the average of two subjects during two exercises at a T_{db} of 41.5 and 42.8° C.

Regardless of clothing worn during the hot months (WBGT above 25° C) the SR was significantly ($P<.05$) greater than during the cool months (WBGT of 10° C or less), as shown in Figure 5. The SR was not significantly different when the WBGT ranged between 11 and 25° C.

Changes in Body Temperature

Rectal Temperature (T_{re})

Changes in T_{re} (i.e., final T_{re} - initial T_{re} = ΔT_{re}) for Loaders, Jammer Drivers, and Crew Chiefs are summarized in Tables 3, 4, and 5. The Loaders had higher T_{re} than the Jammer Drivers and the Crew Chiefs. The greater increase in T_{re} and SR of the Loaders, as compared to the other team members, is related to the high energy expenditure associated with their task.

The rate of rise in T_{re} while performing the task was greater when wearing the CWD ensemble than when wearing fatigues. An example of such change during and after performing a task is shown in Figure 6 for a Loader and in Figure 7 for a Crew Chief. These figures show that the rate of rise in T_{re} is lower in the Crew Chief than in the Loader regardless of the ensemble worn. When the CWD was worn, T_{re} did not show any decline for 30 min after the task was completed; but when fatigues were worn, T_{re} decreased to the preworking level within 30 min. Therefore, alternating work and rest between consecutive tasks can reduce thermal stress and thus, improve performance when fatigues are worn, but will have no significance when the CWD ensemble is worn.

Skin Temperature (T_{sk})

The T_{sk} was measured on only one location, the chest. Tables 6, 7, and 8 summarize T_{sk} measured for all team members during the rapid turnaround, wearing either the CWD ensemble or fatigues; the T_{sk} was consistently higher with the CWD than the fatigues. An example of T_{sk} changes for a Loader during and after a task is shown in Figure 8. The higher T_{sk} with the CWD ensemble may play an important role in increasing SR.

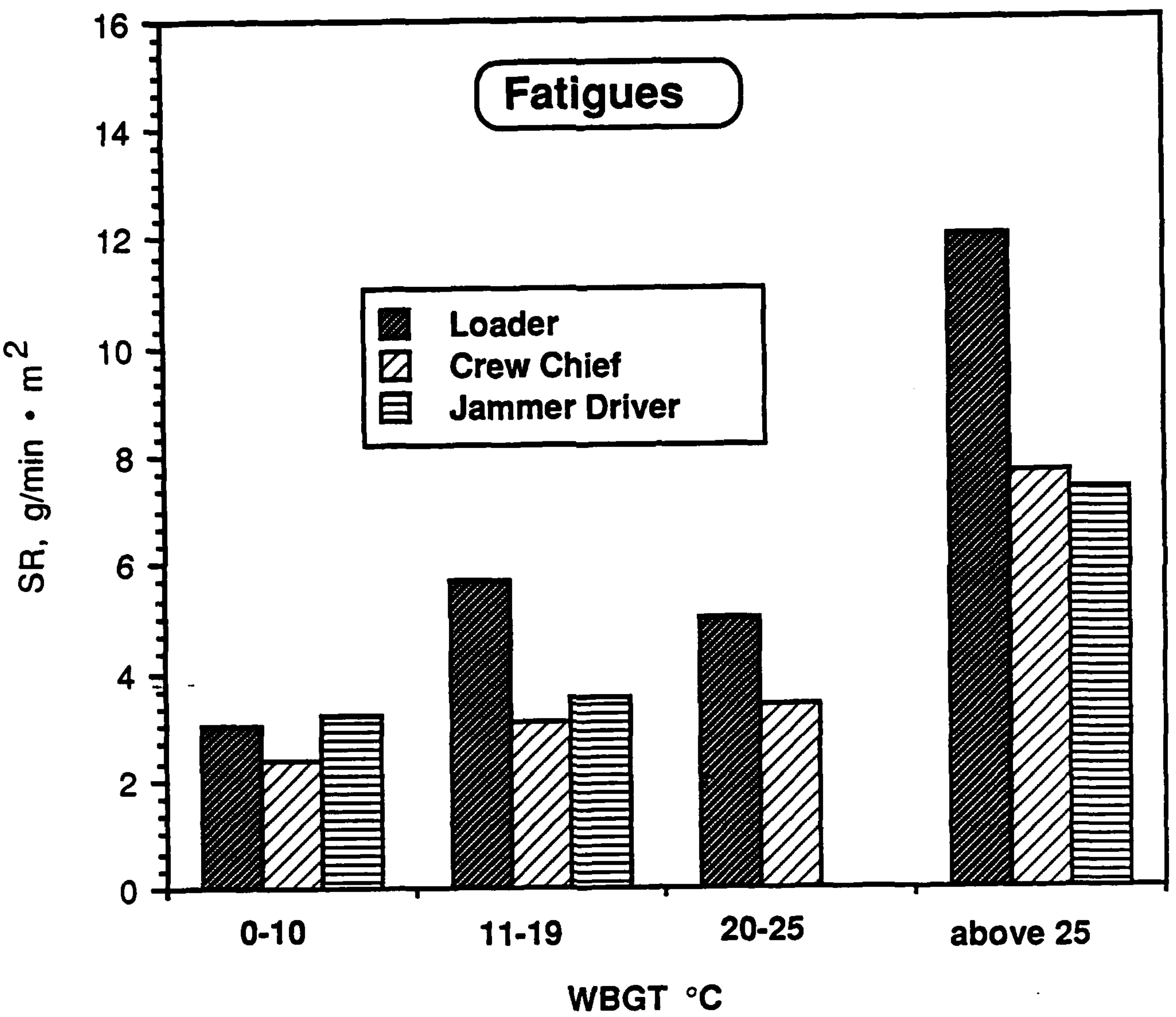

Figure 5. Average sweat rate (SR) of Loaders, Crew Chiefs and Jammer Drivers at a WBGT ranging from 4 to 32° C.

TABLE 3. PHYSIOLOGICAL RESPONSES OF LOADERS 1 AND 2 WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

		CWD			FATIGUES		
Environ Temp, °C	n	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m^2·min)	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m^2·min)
03–15	19	16.8 ± 4.2	0.4 ± 0.4	5.2 ± 3.26	15.8 ± 3.5	0.2 ± 0.2	4.2 ± 1.04
15–30*	9	16.6 ± 2.6	0.5 ± 0.09	6.3 ± 2.2	14.6 ± 3.4	0.12 ± 0.09	4.24 ± 3.2
15–30**	5	18.1 ± 1.5	0.7 ± 0.1	8.1 ± 0.6	17.8 ± 4.2	0.4 ± 0.3	4.7 ± 0.57
30–46	7	17.0 ± 1.8	0.9 ± 0.2	13.9 ± 3.6	16.7 ± 3.6	0.6 ± 0.2	10.9 ± 2.3

*Experiments completed during January through April 1984

**Experiments completed during August and September 1983

SR = Sweat Rate

ΔT_{re} = Final T_{re} minus Initial T_{re}

± = Standard deviation

n = Number of measurements

TABLE 4. PHYSIOLOGICAL RESPONSES OF JAMMER DRIVERS WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

		CWD			FATIGUES		
Environ Temp, °C	n	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m²·min)	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m²·min)
03-15	11	11.9 ± 3.2	0.1 ± 0.1	3.9 ± 1.5	12.0 ± 3.7	0.1 ± 0.3	3.3 ± 1.5
15-30*	7	11.7 ± 1.9	0.06 ± 0.08	5.4 ± 2.1	13.0 ± 2.0	0.0 ±	3.4 ± 2.4
15-30**	4	11.4 ± 3.9	0.3 ± 0.2	6.6 ± 2.7	-	-	-
30-46	5	12.3 ± 2.4	0.6 ± 0.1	9.1 ± 1.9	11.3 ± 3.6	0.4 ± 0.1	7.4 ± 3.0

*Experiments completed during January through April 1984

**Experiments completed during August and September 1983

SR = Sweat Rate

ΔT_{re} = Final T_{re} minus Initial T_{re}

± = Standard deviation

n = Number of measurements

TABLE 5. PHYSIOLOGICAL RESPONSES OF CREW CHIEFS WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

	CWD				FATIGUES		
Environ Temp, °C	n	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m^2·min)	$\dot{V}_{O_2}$, ml/(kg·min)	ΔT_{re}, °C	SR g/(m^2·min)
03-15	15	10.7 ± 2.4	0.2 ± 0.1	3.2 ± 1.7	9.8 ± 2.3	0.1 ± 0.09	2.1 ± 1.0
15-30*	8	9.9 ± 5.8	0.2 ± 0.08	4.4 ± 1.5	10.8 ± 1.4	0.18 ± 0.10	3.7 ± 2.1
15-30**	5	10.7 ± 3.5	0.3 ± 0.2	5.0 ± 2.1	-	-	-
30-46	7	10.7 ± 5.3	0.4 ± 0.1	8.4 ± 1.7	10.6 ± 3.6	0.3 ± 0.1	6.9 ± 2.0

*Experiments completed during January through April 1984

**Experiments completed during August and September 1983

SR = Sweat Rate

ΔT_{re} = Final T_{re} minus Initial T_{re}

± = Standard deviation

n = Number of measurements

TABLE 6. SKIN TEMPERATURE (T_{sk}) AND HEART RATE (HR) OF LOADERS 1 AND 2 WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

Environ Temp, °C	CWD					Fatigues				
	n	T_{sk}		HR (bpm)		n	T_{sk}		HR (bpm)	
		before	after	before	after		before	after	before	after
03 - 15	19	33.6 ± 1.8	34.8 ± 0.9	68 ± 6	124 ± 8	13	33.2 ± 2.1	33.0 ± 0.8	70 ± 8	120 ± 6
15 - 30*	9	33.4 ± 1.2	34.8 ± 0.6	71 ± 6	131 ± 4	11	33.4 ± 0.8	33.2 ± 0.4	71 ± 5	118 ± 8
15 - 30**	5	34.2 ± 0.9	35.9 ± 0.4	73 ± 4	136 ± 7	3	33.8 ± 1.0	33.2 ± 0.6	73 ± 6	124 ± 4
30 - 46	7	34.4 ± 0.8	36.2 ± 0.6	70 ± 8	149 ± 6	7	34.8 ± 0.6	33.4 ± 0.4	71 ± 5	136 ± 6

*Experiments completed during January-April 1984

**Experiments completed during August and September 1983

± = Standard deviation

n = Number of measurements

TABLE 7. SKIN TEMPERATURE (T_{sk}) AND HEART RATE (HR) OF JAMMER DRIVERS WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

Environ Temp, °C	CWD					Fatigues				
	n	T_{sk}		HR (bpm)		n	T_{sk}		HR (bpm)	
		before	after	before	after		before	after	before	after
03 - 15	11	33.1 ± 1.1	34.9 ± 0.7	76 ± 8	121 ± 6	7	33.4 ± 1.2	33.0 ± 0.6	72 ± 4	102 ± 7
15 - 30*	7	33.4 ± 0.8	34.6 ± 0.5	72 ± 6	124 ± 9	5	33.0 ± 1.0	33.2 ± 0.6	70 ± 6	109 ± 5
15 - 30**	4	33.8 ± 0.9	35.2 ± 0.6	74 ± 8	122 ± 5	4	34.2 ± 1.0	33.6 ± 0.7	73 ± 5	118 ± 7
30 - 40	5	34.4 ± 0.8	35.8 ± 0.5	71 ± 7	136 ± 6	5	34.6 ± 0.9	33.4 ± 0.6	70 ± 6	128 ± 4

*Experiments completed during January-April 1984

**Experiments completed during August and September 1983

± = Standard deviation

n = Number of measurements

TABLE 8. SKIN TEMPERATURE (T_{sk}) AND HEART RATE (HR) OF CREW CHIEFS WEARING CWD ENSEMBLE OR FATIGUES WHILE PERFORMING A RAPID TURNAROUND UNDER DIFFERENT ENVIRONMENTAL TEMPERATURES

Environ Temp, °C	CWD					Fatigues				
	n	T_{sk}		HR (bpm)		n	T_{sk}		HR (bpm)	
		before	after	before	after		before	after	before	after
03 - 15	15	33.4 ± 1.1	34.8 ± 0.5	72 ± 4	89 ± 4	17	33.2 ± 0.9	33.4 ± 0.4	72 ± 6	88 ± 3
15 - 30*	8	34.1 ± 0.9	35.6 ± 0.3	73 ± 6	94 ± 5	12	33.8 ± 0.6	33.2 ± 0.5	71 ± 4	86 ± 5
15 - 30**	5	33.8 ± 0.6	35.4 ± 0.3	72 ± 5	98 ± 7	4	34.2 ± 0.9	33.0 ± 0.6	72 ± 5	92 ± 6
30 - 40	7	34.2 ± 0.7	35.6 ± 0.4	72 ± 4	102 ± 6	5	34.6 ± 0.8	33.8 ± 0.6	70 ± 3	106 ± 4

*Experiments completed during January-April 1984
**Experiments completed during August and September 1983
± = Standard deviation
n = Number of measurements

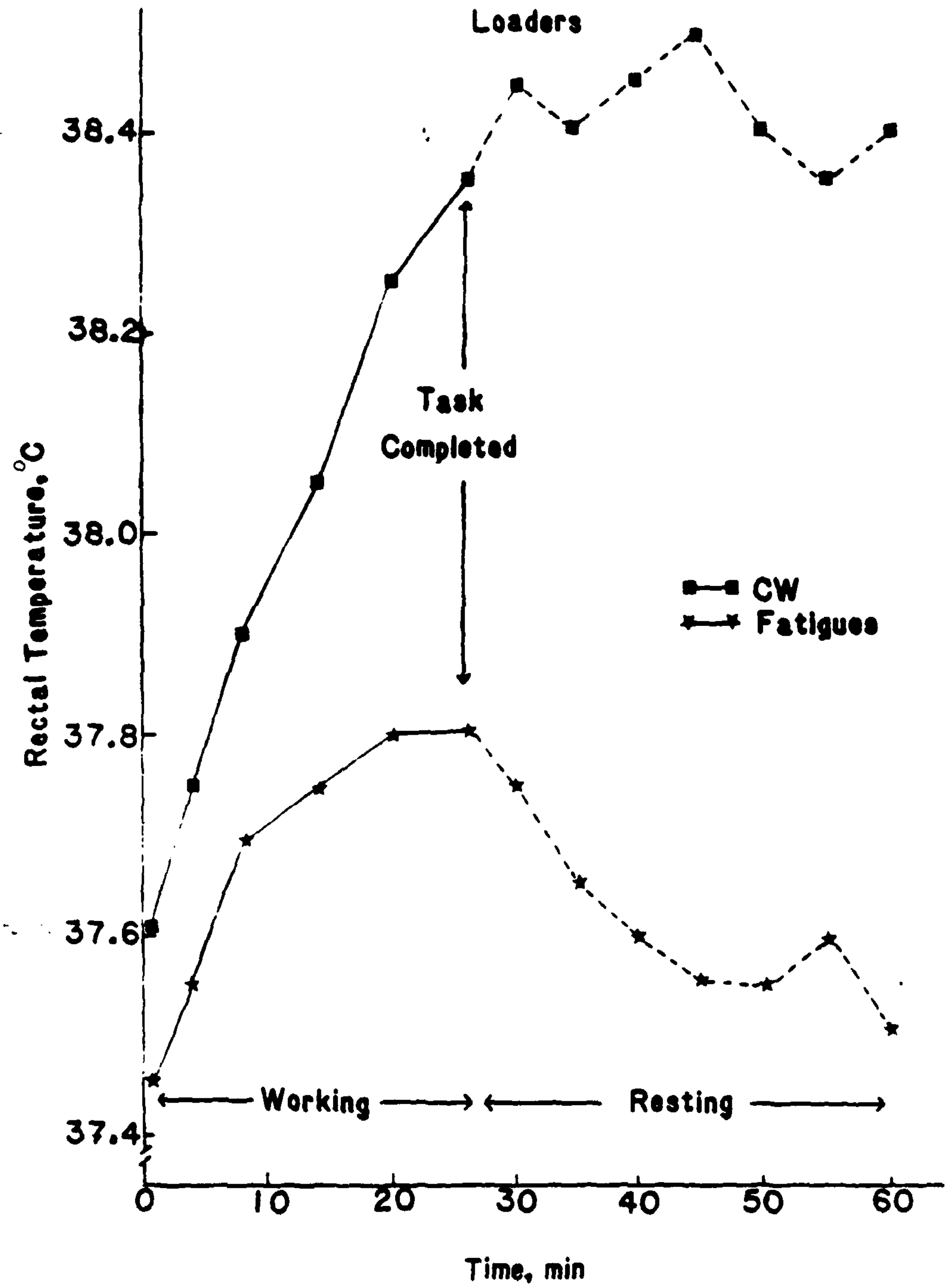

Figure 6. Changes in rectal temperature of two Loaders during and after a turnaround exercise; one was wearing fatigues, the other a CWD ensemble. Both subjects completed the exercise at a T_{db} of 44.2° C (WBGT = 31.9° C) and then rested in the shade of the F-16.

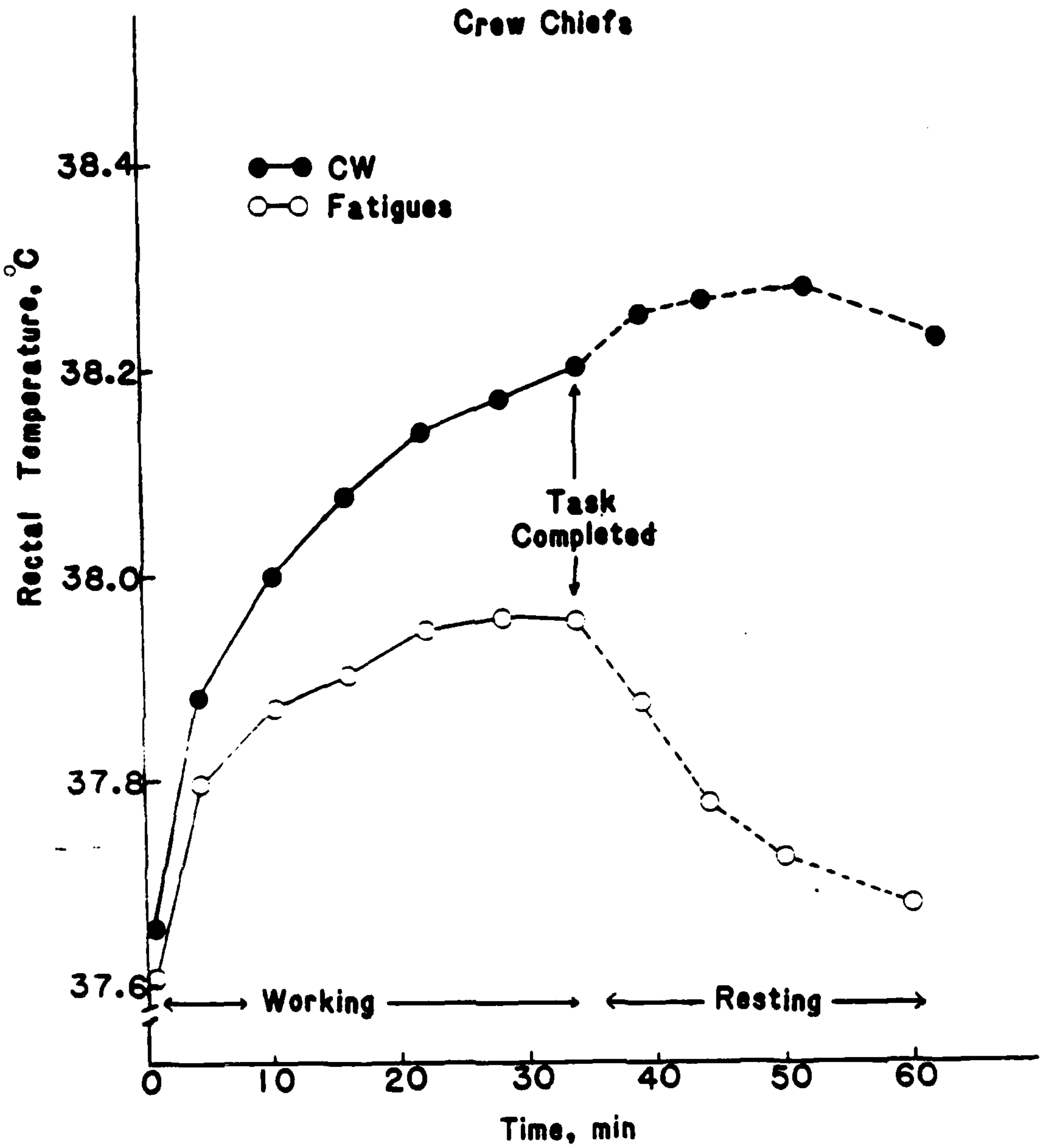

Figure 7. Changes in rectal temperature of two Crew Chiefs during and after a turnaround exercise; one was wearing fatigues and the other, the CWD ensemble. Both team members completed the exercise at a T_{db} = 43.8° C (WBGT = 31.6° C) and then rested in the shade of the F-16.

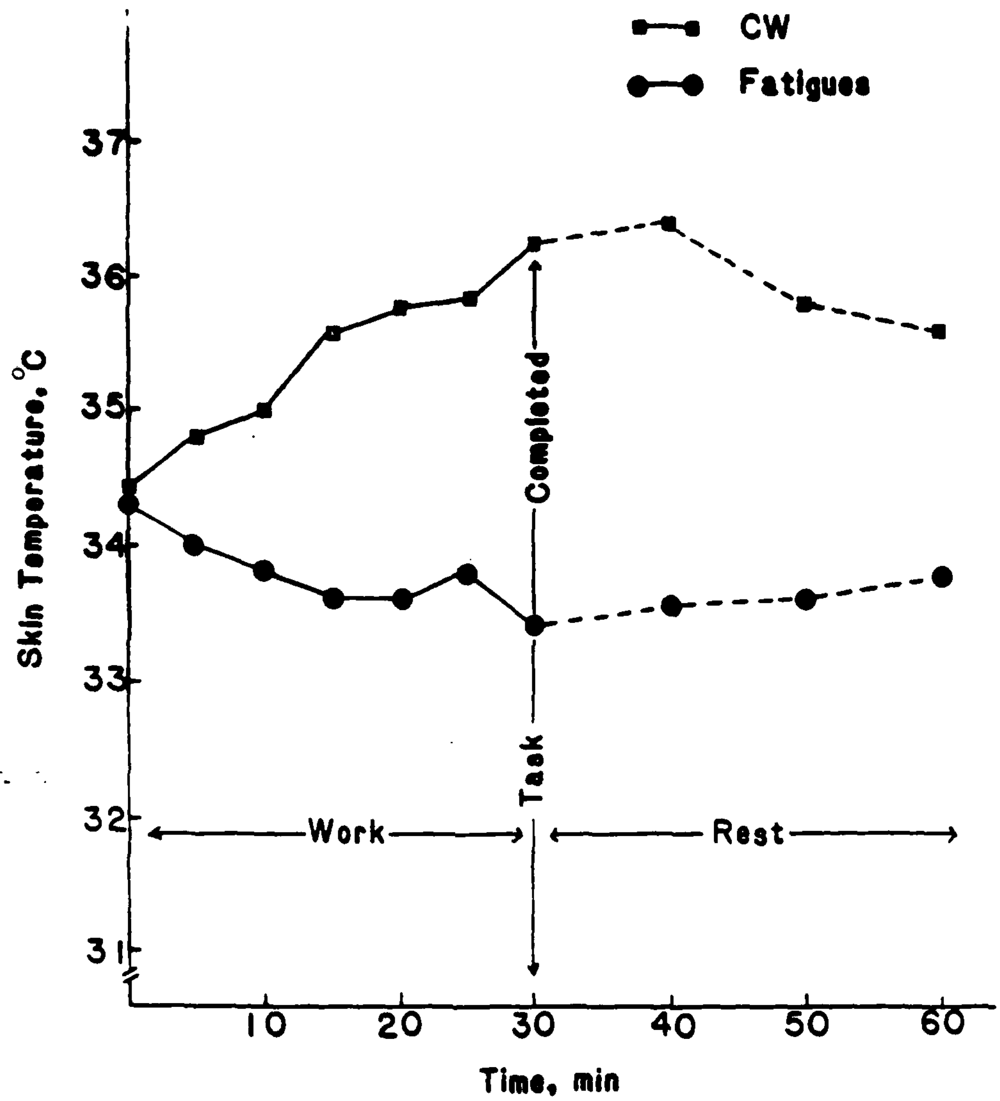

Figure 8. Changes in chest-skin temperature of two Loaders during and after a turnaround exercise; one was wearing fatigues, the other a CWD ensemble. The conditions of the exercise are the same as described for Figure 6.

Heart Rate

The average final heart rate (FHR) for each team member under all conditions is summarized in Tables 6, 7, and 8. For all team members the FHR was higher during the summer season than the winter; wearing the CWD ensemble, as compared to fatigues, caused a significant rise in FHR ($P<.05$). During both summer and winter, the FHR of the Loaders and Jammer Drivers when wearing CWD ensembles was significantly higher ($P<.05$) than of the Crew Chiefs.

An example of the rise in heart rate (HR) during a rapid turnaround is shown in Figure 9 for a Loader, Jammer Driver and Crew Chief. After 10 min of the exercise, the Crew Chief's HR reached a steady state, but the HR for the Loader and Jammer Driver continued to rise throughout the exercise. The high HR of the Loader coincided with the increased $\dot{V}_{O_2}$, T_{re}, T_{sk}, and SR.

The changes in HR during and after the exercise is shown in Figure 10 for two Loaders, one wearing the CWD ensemble and the other wearing fatigues. Both HRs rose throughout the exercise. After the task was completed the HR of the Loader wearing fatigues returned to resting values within 10-20 min; but for the Loader wearing the CWD ensemble, the HR decreased only from 148 to 128 after 10 min of resting and remained above 124 bpm for 30 min. As demonstrated with T_{re} (Figures 6 and 7), resting after completing a turnaround did not reduce heat stress when the CWD ensemble was worn.

Individual Physical Work and Tolerance Time

During the hot months, each individual participated in only one rapid turnaround exercise per day. The data on $\dot{V}_{O_2}$, T_{re}, T_{sk}, HR, and SR suggest that the Loaders wearing CWD ensembles may not safely be able to complete more than two consecutive turnaround exercises. At the end of different exercises, one Loader had a T_{re} of 39.3° C and another loader had 39.5° C. Both felt dizzy and slightly disoriented; one vomited.

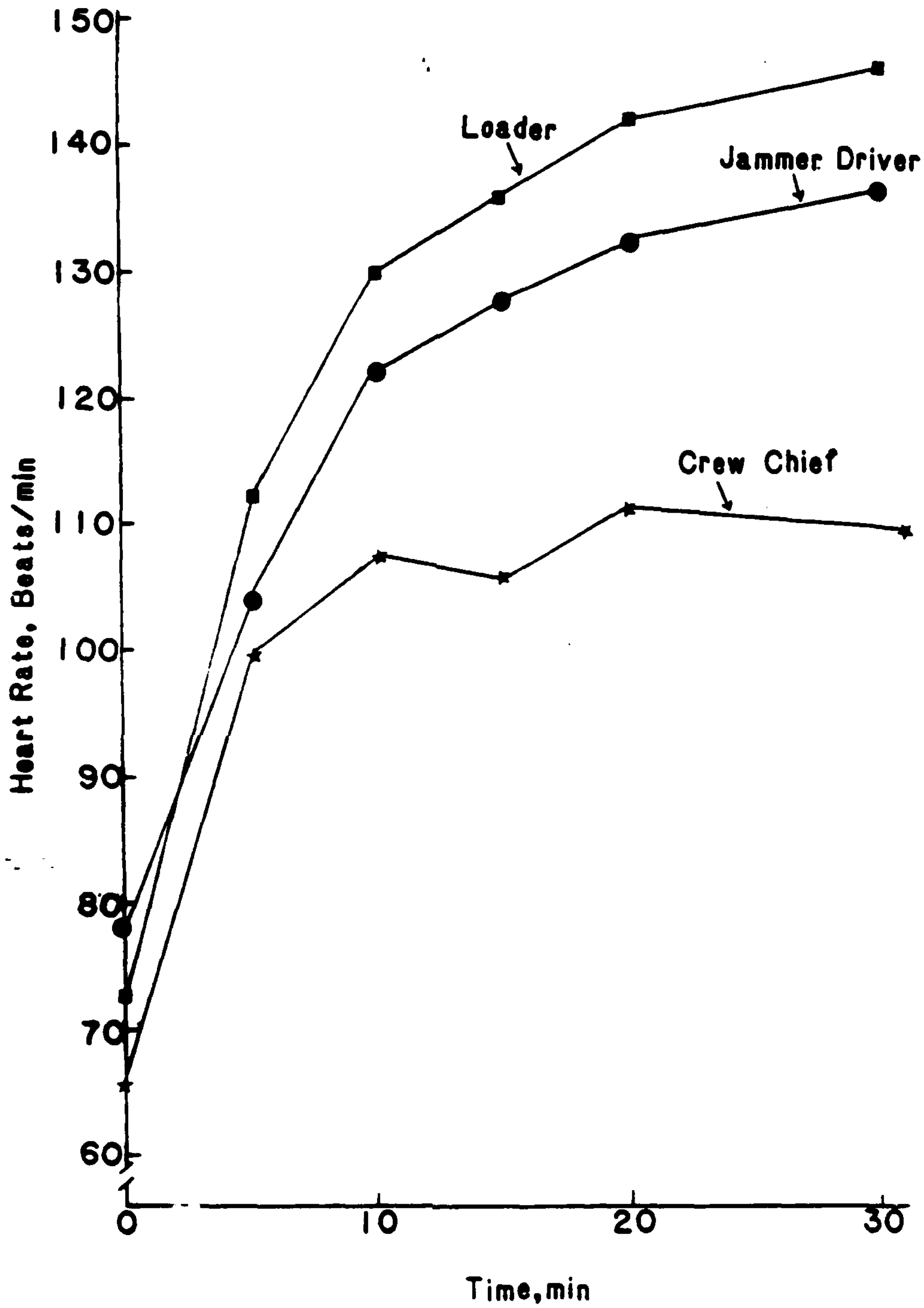

Figure 9. Changes in heart rate for a Loader, a Jammer Driver, and a Crew Chief while wearing a CWD ensemble during a turnaround exercise. The exercise was completed at a T_{db} of 41.6° C (WBGT = 31.1° C).

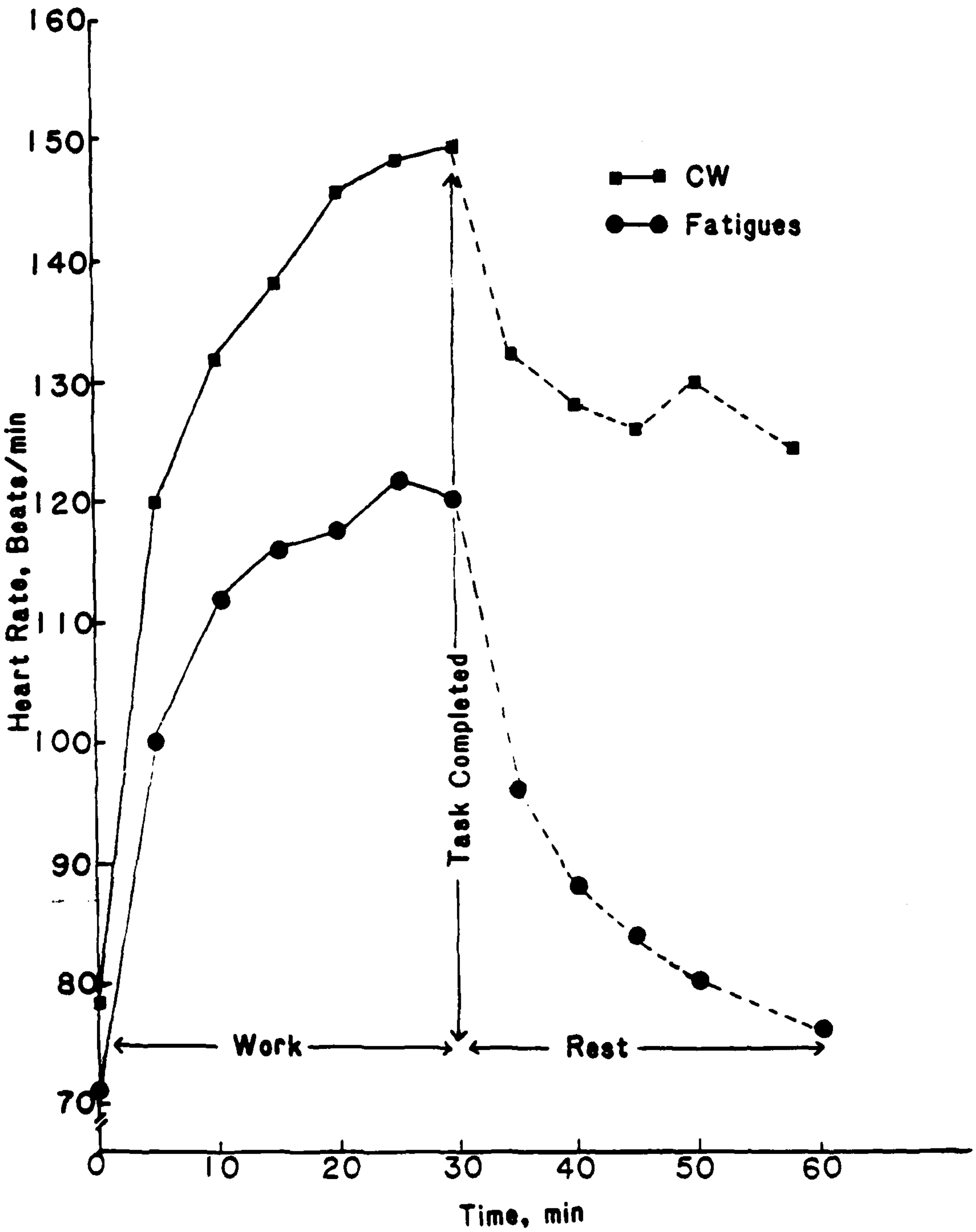

Figure 10. Changes in heart rate of two Loaders during and after a turnaround exercise; one was wearing fat:゛"es, the other a CWD ensemble. Both subjects completed the exercise at a T_{db} of 41.6° C (WBGT=31.1° C) and then rested in the shade of the F-16.

No other such incidences occurred. Just how long each of the five team members can work wearing the CWD ensemble in a hot environment remains unanswered.

During the cool months, with air temperatures ranging from 3 to 15° C, the Loaders wearing CWD ensembles completed two or three continuous turnaround exercises. After the second and/or third turnaround exercise was completed, the average rise in T_{re} was less than 0.5° C. In 5 days the Crew Chiefs completed four turnaround exercises while wearing the CWD ensemble and rises in T_{re} ranged from 0.2 to 0.4° C.

We did not attempt to carry out more than four consecutive exercises on the same day, so the tolerance time of each team member cannot be determined from the available data. The data suggest, however, that in a hot environment (WBGT about 25° C) the tolerance time is greatly reduced for a team member working while wearing the CWD ensemble. Considering the rate of rise in T_{re} and HR (Figures 6, 7, 9, and 10) tolerance time for the Loaders is probably about 40-50% less than that of the Crew Chiefs.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

At a WBGT below 15° C, a team of five members wearing the CWD ensemble could complete four rapid turnaround exercises without any noticeable heat stress. At a WBGT of about 25° C, however, and based on rate of rise in T_{re}, T_{sk}, and HR, the tolerance time of Loaders wearing the CWD will probably not exceed two consecutive exercises, i.e., 1 h.

Tolerance time of Loaders wearing the CWD ensemble in a hot environment (WBGT above 25° C) was much less than that of the Crew Chiefs. The lower tolerance time of the Loaders is related to their more rapid rise in T_{re} and HR resulting from their higher $\dot{V}_{O_2}$ throughout the exercise.

The Loaders had higher $\dot{V}_{O_2}$, T_{re}, T_{sk}, HR, and SR than the Crew Chiefs. For each group the $\dot{V}_{O_2}$ was similar under different ambient temperatures regardless of the ensemble (fatigues or CWD) worn. The T_{re}, T_{sk}, HR, and SR were higher when the CWD ensemble was worn.

Recommendations

In case of a shortage in groundcrew for consecutive rapid turnaround exercises in a hot, dry environment, we recommend the following: (a) replace Loaders more frequently than the Crew Chiefs, (b) rotate tasks of Crew Chiefs and Loaders during consecutive turnaround operations if possible, and (c) cool the CWD ensemble of the Loaders during a rest period of 30 min between operations, if possible.

The data presented in this report were collected for a rapid turnaround operation performed only on the F-16. Our subjects informed us that the rapid turnaround is performed differently when loading other types of bombs and missiles, using other fighters such as the F-15 or F-4, and performing the task in different locations such as Europe vs. Southeast Asia. Therefore, our recommendations may not always be applicable when the turnaround task requires significant variations from the exercise described in this report. Because the rapid turnaround differs according to the aircraft being serviced, the ammunition, and the locale, we recommend that similar data be obtained using other fighters, different types of bombs and missiles, and different locations or terrains.

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APPENDIX

PHOTOGRAPHS OF GROUNDCREW PERFORMING TURNAROUND TASKS

Figure No.	Description
A-1	Crew Chief-1 wearing CWD and Crew Chief-2 wearing fatigues. Both are pushing an F-16 to the loading location. Crew Chief-1 is fitted with an apparatus to measure the energy cost of the task.
A-2	One Crew Chief wearing CWD and observing other members of the team. The subject is fitted for measurement of $\dot{V}_{O_2}$.
A-3	One Loader is pulling the ammunition cart to the F-16.
A-4	One Loader is lifting the ammunition to load the gun.
A-5	One Loader is loading the gun.
A-6	One Loader (in CWD) helping the Jammer Driver (in CWD) to load and transport a bomb to the F-16. Both subjects are fitted for measurement of $\dot{V}_{O_2}$.
A-7	Two Loaders in fatigues are loading the bombs.
A-8	The two Loaders and the Jammer Driver are lifting a missile.
A-9	The Loaders and Jammer Driver are carrying a missile to the F-16.
A-10	One missile is being attached to the F-16.
A-11	An illustration of measurements of expired gas volume and collection of air samples for analysis under field conditions.
A-12	An illustration of periodic (10 min) measurements of rectal temperature (T_{re}) during the rapid-turnaround exercise. The T_{re} is continuously recorded using a Medilog miniature cassette recorder.
A-13	An illustration of measurements of total body sweat rate using an electronic battery-operated scale sensitive to ± 10 g.

Figure A-1. Crew Chief-1 wearing CWD and Crew Chief-2 wearing fatigues. Both are pushing an F-16 to the loading location. Crew Chief-1 is fitted with an apparatus to measure the energy cost of the task.

Figure A-2. One Crew Chief wearing CWD and observing other members of the team. The subject is fitted for measurement of $\dot{V}_{O_2}$.

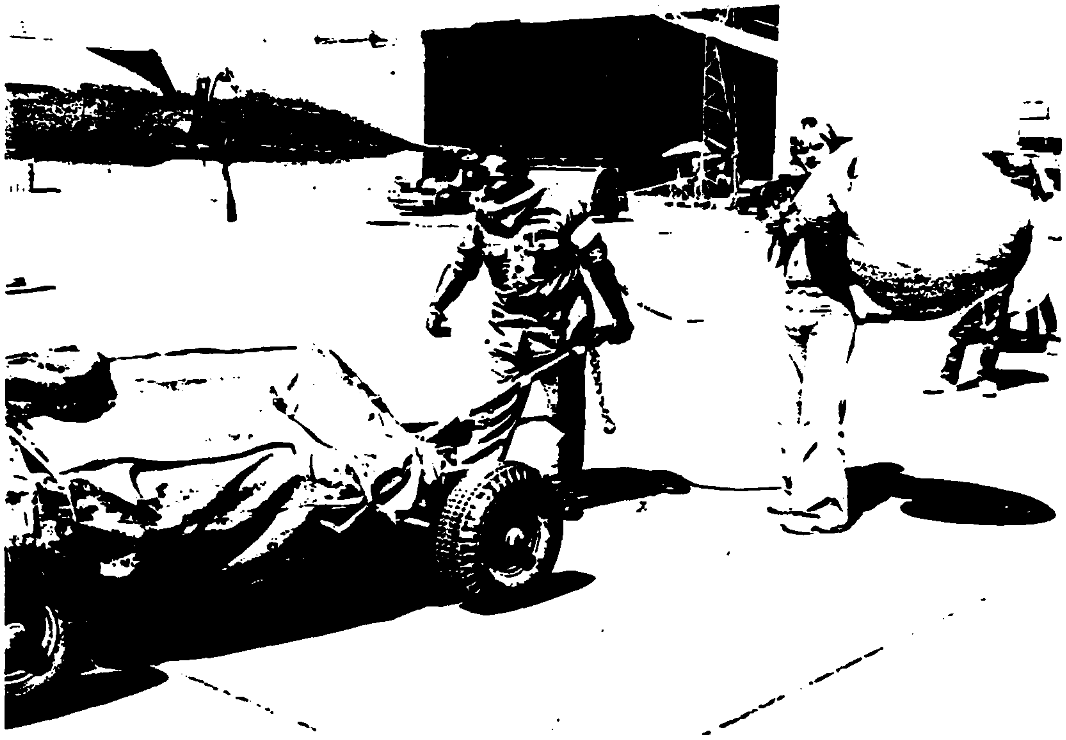

Figure A-3. One Loader is pulling the ammunition cart to the F-16.

Figure A-4. One Loader is lifting the ammunition to load the gun.

Figure A-5. One Loader is loading the gun.

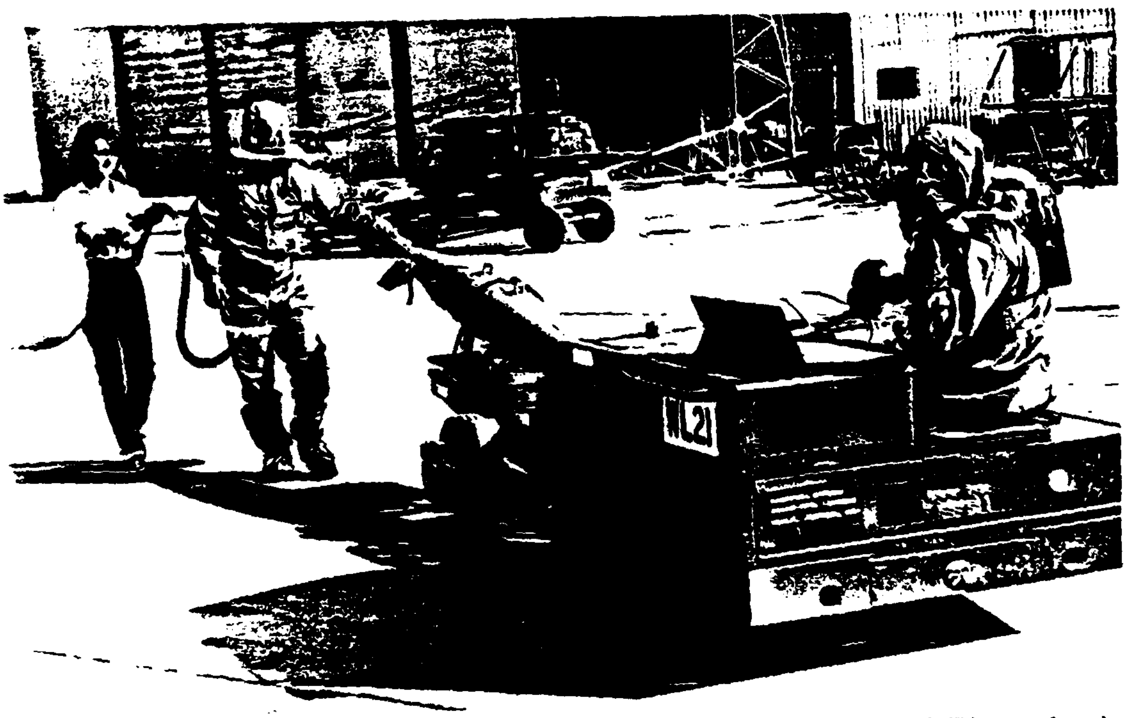

Figure A-6. One Loader (in CWD) helping the Jammer Driver (in CWD) to load and transport a bomb to the F-16. Both subjects are fitted for measurement of $\dot{V}_{O_2}$.

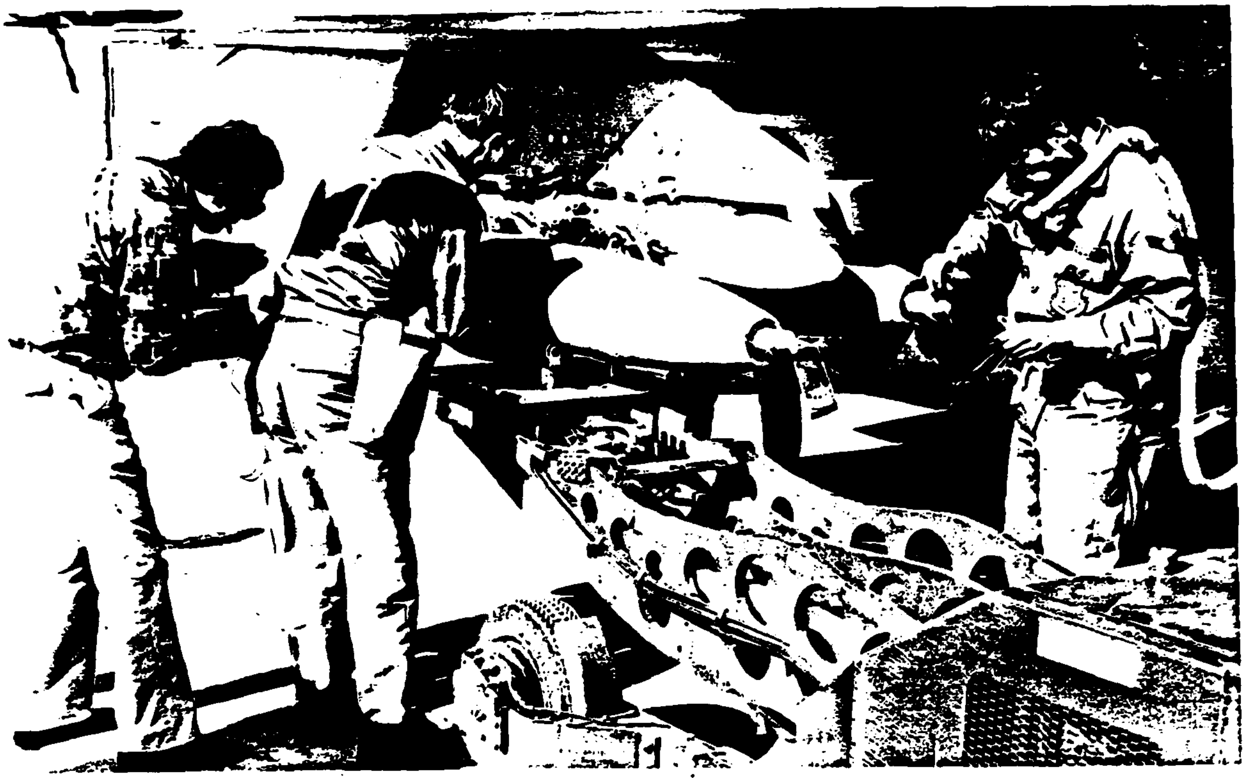

Figure A-7. Two Loaders in fatigues are loading the bombs.

Figure A-8. The two Loaders and the Jammer Driver are lifting a missile.

Figure A-9. The Loaders and Jammer Driver are carrying a missile to the F-16.

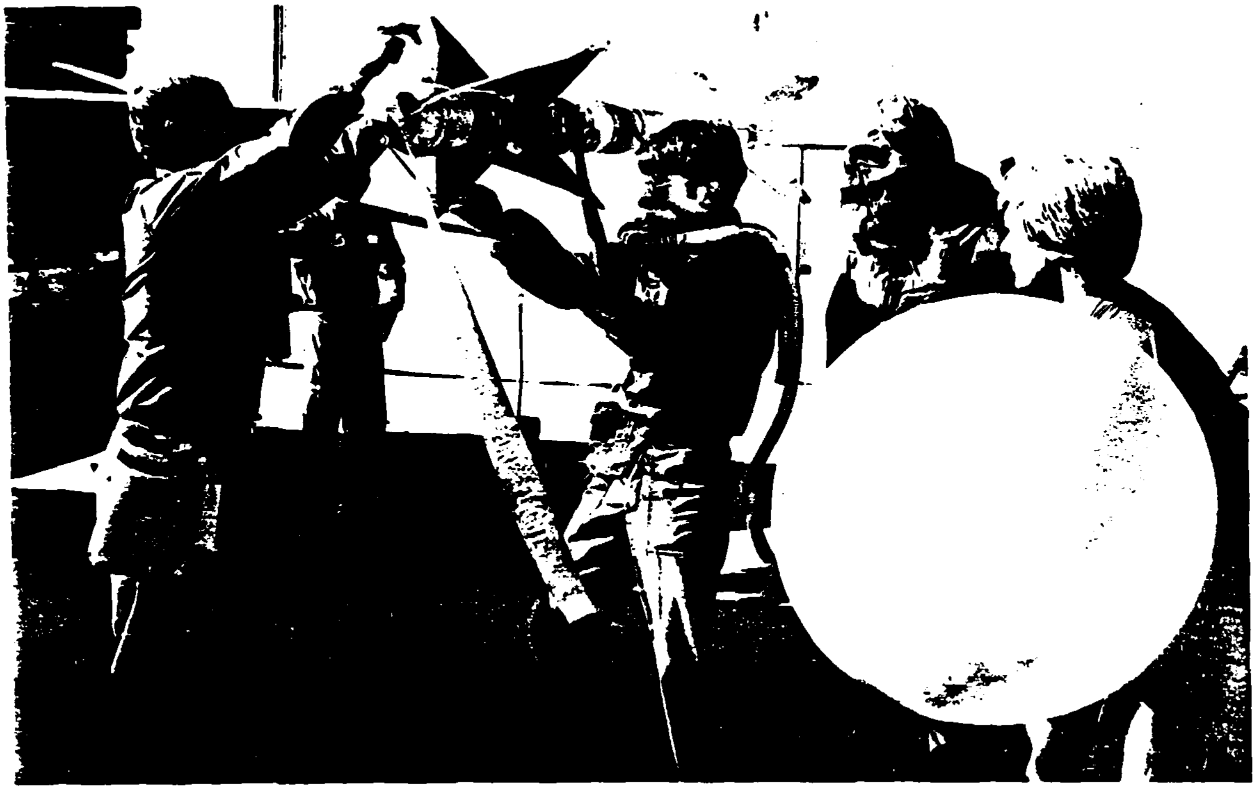

Figure A-10. One missile is being attached to the F-16.

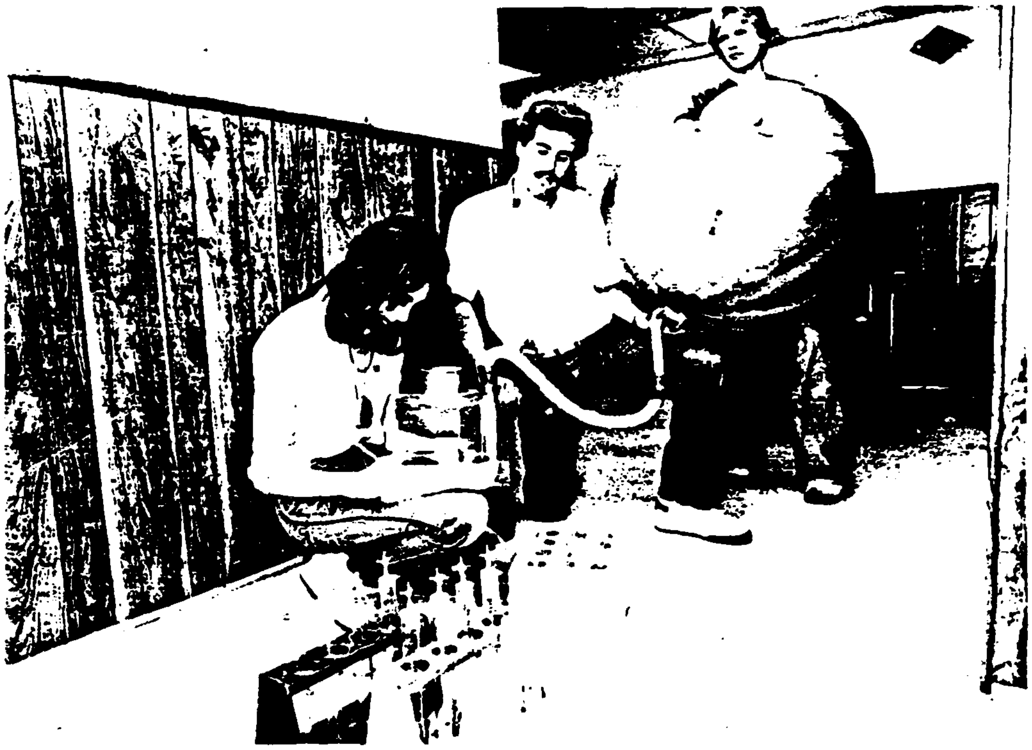

Figure A-11. An illustration of measurements of expired gas volume and collection of air samples for analysis under field conditions.

Figure A-12. An illustration of periodic (10 min) measurements of rectal temperature (T_{re}) during the rapid turn-around exercise. The T_{re} is continuously recorded using a Medilog miniature cassette recorder.

Figure A-13. An illustration of measurements of total body sweat rate using an electronic battery-operated scale sensitive to ± 10 g.