II. Effect of Different Levels of Ambient Carbon Monoxide on Maximal Work Capacity

Introduction

Previous investigations (10, 12, 13, 14, 15) suggested that a linear decline in aerobic power ($\dot{V}_{O_2\ max}$) occurred with a progressive increase in carboxyhemoglobin (%COHb) levels. The requisite COHb levels were obtained prior to the maximum aerobic power test by breathing a high concentration of carbon monoxide -- a bolus (BO) presentation. The resultant COHb levels were between 7 and 33%. The earlier investigations of this project during which young and middle-aged men, smokers and nonsmokers, continuously breathed air containing 50 ppm of CO -- a buildup (BU) presentation -- failed to demonstrate any significant decrease in $\dot{V}_{O_2\ max}$, although the duration of effort in this progressive test was significantly shortened. The COHb levels in these studies were 2.7% for nonsmokers and 4.5 and 5.2% respectively for young and middle-aged smokers. Several possibilities exist to explain these differences. The mode of presentation of CO may be a factor or the level of ambient inspired CO may not have been high enough to have interfered with oxygen transport. There is a necessity to determine the precise level of COHb at which aerobic capacity is impaired and to relate this level to the ambient concentrations of CO present in our air environment.

Methods

Four healthy adult male volunteers aged 24-33 years were subjects for the present investigation. Three were nonsmokers and the fourth abstained from his pipe smoking for a minimum of 12 hours prior to each test. They had been engaged in numerous previous studies and were well

versed in the experimental procedures. All subjects were screened for cardiovascular and pulmonary abnormalities.

The maximum aerobic capacity was determined utilizing the progressive test described by Drinkwater and Horvath (1). Each subject performed three $\dot{V}_{O_2\ max}$ tests for the buildup experiments (BU), which consisted of breathing either (A) filtered air, (B) 75 ppm CO in filtered air, or (C) 100 ppm CO in filtered air. The conditions were presented in random order and in a single blind mode so that the subjects were unaware of the conditions of the exposure. The inspired level of CO was maintained within $\pm$ 3 ppm of the required level for the entire exposure condition leading to a gradual increase in COHb over time. There was one week between each exposure. The subjects than repeated the three exposures in a different random order with the exception that a preliminary "bolus" (BO) inhalation of CO was given to bring the pre exercise COHb level to that obtained at the end of the previous "BU" tests. During this second series the COHb levels were maintained at the required levels throughout the entire test within 0.1% during (B) tests and 0.12% during (C) exposures. The technique employed to maintain these levels has been described elsewhere (25).

Blood volumes were measured to obtain total body hemoglobin. On the day of the BU tests the subject was seated and a blood sample taken for analysis of its hemoglobin, lactate (4), hematocrit, plasma protein, and CO content (5). The subject was then connected to the ECG monitoring leads (V4) and started breathing through an open circuit system. Thirteen minutes later another blood sample was obtained and analyzed as above. At the fifteenth minute the subject began walking on the treadmill at 3.4 mph with the grade automatically being increased 1% each minute. Immediately upon exhaustion the subject was seated in a chair for a 15 minute recovery

to determine the oxygen debt. A third blood sample was secured at the fourth minute of recovery. In the BO studies the subject was connected to a closed circuit system for a preliminary seated rest period of 15 minutes while his COHb levels were brought to the required level. He breathed 100% oxygen, and 10% of the previously determined quantity of CO for filtered air was injected into the system each minute for the first 10 minutes. Blood samples were obtained to determine the COHb levels. At the end of this 15 minute period he then transferred to the open circuit system which provided the maintenance level of ambient CO (25). Additional blood samples were taken as for the BU tests and the same protocol of rest, exercise, and recovery followed.

During rest, exercise, and recovery, ventilatory volumes, respiratory rates, oxygen and carbon dioxide contents of expired air were continuously monitored, averaged, and recorded by a PDP-12 computer connected on line to the respective analyzers. Oxygen percentage was analyzed using a Servomex analyzer, and CO_2 by an infrared analyzer. Ventilatory volumes were monitored with a dry gas meter, and respiratory rate was obtained using a thermistor in the mouthpiece. Aliquot expired air samples were obtained at intervals for direct analysis by gas chromatography as an independent check on the computerized data. Inspired CO was continuously monitored using a long-path IR analyzer (Beckman 315B). The electrocardiogram was monitored on an oscilloscope with heart rates obtained from the ECG recorded during the last ten seconds of each minute.

Data were analyzed using a two-factor analysis of variance with repeated measures across exposure conditions and CO presentation modes. Where significant interactions were found a further analysis was made of simple main effects followed by a Newman-Keuls test of ordered means

at the 0.05 and 0.10 levels of confidence (6). Variables selected for analysis included all physiological variables measured at $\dot{V}_{O_2\ max}$ and blood parameter values obtained prior to and following the exercise tests.

Results

The subjects' physical characteristics, including their blood volumes and CO dilution spaces, are presented in Table 8. The values were within the range of the normal population with the exception that the plasma volumes of all subjects were greater than the average (26). Table 9 summarizes the average $\dot{V}_{O_2\ max}$ and total exercise time obtained during each condition as well as the ventilatory volumes and heart rates at $\dot{V}_{O_2\ max}$. Regardless of the mode of presentation of CO, the $\dot{V}_{O_2\ max}$ was lower ($P < 0.10$) when COHb was over 4.0%. All four subjects exhibited decreased aerobic power under these conditions. No significant differences in $\dot{V}_{O_2\ max}$ from control conditions were observed when subjects breathed 75 ppm CO or attained the same level of carboxyhemoglobin (3.2-3.4% by the bolus and maintenance procedure). However, ventilatory volumes were significantly lower during all four CO exposures than during the filtered air tests. It should be noted that the subjects walked 1-2 minutes longer in the latter condition. These lower times in which CO was being breathed were significantly lower ($P < 0.05$). The difference in work time between the lower and higher final COHb levels was also significant. No significant differences between conditions were obtained for heart rate, ventilatory equivalent ratio, or excess carbon dioxide at $\dot{V}_{O_2\ max}$. Oxygen debt was similar under all conditions. At $\dot{V}_{O_2\ max}$ the only differences observed between "bolus" and buildup" presentations of CO were for the respiratory exchange ratio (R), which was lower in "BO" ($\bar{X} = 1.02$) than in "BU" ($\bar{X} = 1.04$), $P < 0.10$, and for tidal volume, which was higher in "BO" ($\bar{X} = 2.73$ liters) than in "BU" ($\bar{X} = 2.66$ liters),

TABLE VIII

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Age (years)	Wt (kg)	S.A. (m^2)	Blood Volumes			THb (gm)	CO dilution*
				Total (ℓ)	RBC (ℓ)	Plasma (ℓ)		(ℓ)
1	24	61.1	1.65	5.40	2.09	3.32	698	0.970
2	28	76.8	2.00	6.26	2.37	3.90	747	1.038
3	29	77.0	2.04	6.69	2.86	3.83	882	1.225
4	33	79.3	1.96	6.31	2.29	4.02	781	1.085

*Total Hb x 1.389

TABLE IX

THE AVERAGE $\dot{V}_{O_2\ max}$ AND VENTILATION AND HEART RATES AT $\dot{V}_{O_2\ max}$ AS WELL AS TOTAL TIME WALKED DURING THE THREE CONDITIONS OF EXPOSURE AND TWO MODES OF PRESENTATION. (MEANS AND STANDARD ERROR OF THE MEANS).

Condition		$\dot{V}_{O_2\ max}$		$\dot{V}_E$ BTPS		Heart Rate		Time Walked	
		BU*	BO**	BU	BO	BU	BO	BU	BO
		(ℓ/min)		(ℓ/min)		(beats/min)		(min)	
A	$\bar{X}$	3.69	3.73	119.6	119.4	189.0	190.0	24.0	24.0
	$SE_{\bar{X}}$	±0.16	±0.10	±6.6	±2.6	±8.4	±5.3	±0.47	±0.47
B	$\bar{X}$	3.51	3.80	103.0	116.5	185.5	186.8	22.8	23.0
	$SE_{\bar{X}}$	±0.16	±0.14	± 5.9	± 3.1	± 5.6	± 4.0	± 0.29	± 1.2
C	$\bar{X}$	3.43	3.46	109.4	102.9	189.3	183.3	22.6	21.5
	$SE_{\bar{X}}$	±0.08	±0.06	± 4.8	± 5.2	± 8.4	± 3.4	± 0.28	± 0.75
		C < A and B		A > B and C		no significant		A > B and C	
		P < 0.10		P < 0.05		differences		P < 0.05	

* BU - Buildup exposures with A = filtered air, B = breathing 75 ppm CO and C = breathing 100 ppm CO

**BO - Bolus exposures plus maintenance (B), at 17.7 ppm CO, and (C), at 23.6 ppm CO

$P < 0.05$. No consistent differences in any of the measured parameters were observed during the submaximal levels of work during the progression to maximum.

The COHb levels followed the anticipated pattern of the experimental design and clearly demonstrated the ability of the techniques utilized to obtain and maintain the predicted values (Table 10). There was no difference in COHb levels at rest (control) in any of the six tests. The second blood sample (Pre #2) reflected the changes in COHb due to either the "BO" or "BU" condition. In the "BU" experiments the COHb values while breathing 75 or 100 ppm CO were not significantly different over the short time period of quiet sitting. Blood carboxyhemoglobin levels at the end of the rest period in the "BO" state were not significantly different from the final post exercise value obtained during the "BU" experiments. The 4 minute post exercise COHb levels for each condition were significantly different ($P < 0.01$) from each other ($A < B < C$) but there were no differences (B and C) between "BO" and "BU" modes of presentation of CO. This latter occurred despite the progressive increase in ventilatory volumes from 6 to 120 liters per minute under the conditions of the exercise test. Although no differences were observed in resting lactates, the post exercise blood lactates were significantly higher ($P < 0.01$) following the filtered air studies than in any of those in which blood COHb was increased regardless of the mode of presentation of CO.

Discussion

No significant decreases in maximal aerobic capacity were noted until COHb levels exceeded 4.3%. Our previous experiments had shown that $\dot{V}_{O_2\ max}$ was unchanged when COHb levels were approximately 2.7%. On the other hand Ekblom and Huot (10) reported a 9% decrease in $\dot{V}_{O_2\ max}$ when COHb

TABLE X

MEAN VALUES FOR BLOOD PARAMETERS DURING ALL CONDITIONS

Condition*		Hemoglobin (mmoles/ℓ)		Carboxyhemoglobin (%)		Lactate (mEq/ℓ)	
		BU**	BO***	BU	BO	BU	BO
A	Pre #1	8.88	8.65	0.35	0.50	1.82	1.62
	$\pm SE_{\bar{X}}$	0.15	0.15	0.06	0.11	0.21	0.24
	Pre #2	8.70	8.70	0.35	0.50	--	--
	$\pm SE_{\bar{X}}$	0.13	0.12	0.03	0.11	--	--
	Post	9.25	9.35	0.33	0.35	11.05	11.28
	$\pm SE_{\bar{X}}$	0.10	0.14	0.06	0.11	1.77	0.45
B	Pre #1	8.70	8.88	0.38	0.50	1.48	1.24
	$\pm SE_{\bar{X}}$	0.21	0.12	0.05	0.16	0.17	0.22
	Pre #2	8.53	8.83	0.75	3.28	--	--
	$\pm SE_{\bar{X}}$	0.13	0.13	0.03	0.12	--	--
	Post	9.10	9.40	3.35	3.18	9.94	9.59
	$\pm SE_{\bar{X}}$	0.08	0.13	0.14	0.16	0.65	1.23
C	Pre #1	8.83	8.93	0.40	0.48	1.79	1.38
	$\pm SE_{\bar{X}}$	0.13	0.10	0.07	0.12	0.22	0.26
	Pre #2	8.78	8.88	0.90	4.43	--	--
	$\pm SE_{\bar{X}}$	0.20	0.12	0.05	0.28	--	--
	Post	9.30	9.38	4.30	4.25	10.10	8.23
	$\pm SE_{\bar{X}}$	0.15	0.10	0.30	0.29	0.88	1.21

* A = filtered air (FA)
B = 75 ppm CO
C = 100 ppm CO

** BU = "buildup" exposures

***BO = "bolus" exposures

was 7.0%. It would appear that a certain increment in COHb was necessary to modify maximal aerobic capacity. It is interesting to note that certain central nervous system functions (27, 28) are also depressed at approximately this same level (4-5% COHb). These altered capacities have been observed to occur in young nonsmokers. Smokers generally have COHb values around 4-7% and their performances may not be affected in the same manner or to the same degree (28-30). Further investigations utilizing smokers as subjects may indicate that it would be more meaningful to relate the decline in $\dot{V}O_{2\ max}$ to a change in COHb from control levels rather than the absolute value present. Roughton and Darling (31) suggested on theoretical grounds that work capacity would be reduced to zero when COHb reached 45-50%. Although the effect of these higher levels of COHb cannot be confirmed, a review of available data, including that available from this study, indicated that a linear decline in $\dot{V}O_{2\ max}$ does occur when COHb levels range from approximately 4 to 35% (12 - 16) and that this change can be expressed as percent decrease in $\dot{V}O_{2\ max}$ = 0.91 (%COHb) + 2.2.

In the present study there occurred a reduction in work time to exhaustion, 4.9 and 7.0% decreases when COHb levels had attained 3.3 and 4.3% respectively. A similar but more marked reduction in maximum work time had been previously reported (10), a 38% decrease at 7% COHb. The forms of exercise utilized to obtain $\dot{V}O_{2\ max}$, walking vs. running, 20-24 vs. 3-5 minutes, may partially explain the larger differences observed by the latter investigators. In the walking tests, although the subjects were unaware of the composition of the inspired gases, they subjectively reported a greater feeling of tiredness in the legs and considerable cramping when exercising while breathing CO. Whether these subjective impressions were responsible for the earlier termination of the tests

could not be determined but the subjects were accustomed to these maximum performances and apparently ceased activity only when completely exhausted. It was observed that the post exercise blood lactates were significantly lower in the CO tests than in the filtered air conditions in contrast to Ekblom and Huot's (10) findings of no change regardless of level of COHb up to 20%. The different test procedures may provide the only explanation, since in short running maximum tests blood lactates are generally higher than in the more prolonged walking tests. The shorter performance time during CO exposures may also explain the lower lactate levels. It is also possible that the decreased work capacity may be a function of the decreased availability of oxygen to metabolic tissues, since increasing levels of COHb result in concomitant decreases in arterial oxygen saturation and raised levels of venous oxygen saturation (32, 33). Vogel et al. (14) have indicated that at $\dot{V}_{O_2\ max}$ with 20% COHb, the cardiac output had attained the same maximal level as that of the higher $\dot{V}_{O_2\ max}$ when breathing air containing no CO. This high cardiac output was attained through a higher heart rate. In the present study as well as those of others (13-15), maximum heart rates were observed even though COHb varied between 4.3 to 20%. These results do not agree with Ekblom and Huot (10), who found significant decrement in maximum heart rate with increasing levels of COHb. Again this may reflect some differences consequent to different test procedures.

Although some concern must still be held as to methodology of producing elevated COHb levels, it was with some surprise that in the present studies no difference in eventual response was noted in the two modes of presentation of CO. This may be due to our slower presentation of the bolus or it may be that the effect of decreased oxygen delivery is demonstrable

only at or near the maximal capabilities of the subjects. We observed no consistently significant ventilatory or heart rate differences during the progressive increases in energy expenditure of this walking test regardless of the mode of presentation of CO. Both Vogel et al. (14, 15) and Pirnay et al. (13) reported consistently higher heart rates for given selected submaximal work loads and increased ventilatory volume exchange per unit of oxygen uptake.

The results of the present study suggest that a critical level of COHb must be present before significant physiological alterations could be demonstrated. They further exhibited that the absolute level may be more important than the mode of presentation, at least at low levels of COHb and in nonsmokers. The coincidence of deteriorated performance as indicated by decreased maximal aerobic power and depression of certain central nervous system functions when COHb levels are about 4-5% may be more than suggestive.

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III. Effect of Carbon Monoxide and Peroxyacetylnitrate on Man's Physiological Ability to Perform Long Term Work

(a) Metabolic, cardiovascular, and thermoregulatory responses

Introduction

Investigations of the physiologic responses to air pollutants in human subjects has been restricted for the most part to short term work at submaximum work loads under neutral temperatures (1-3). The results of the above reported experiments (see Sections I and II) suggests that at maximal work no substantial effect from exposure to 0.27 ppm peroxyacetylnitrate or 50 and 75 ppm carbon monoxide was observable. However, it was noted that 100 ppm carbon monoxide (resulting in blood carboxyhemoglobin levels of > 4.3%) slightly reduced maximal aerobic power. It was noted previously (page 13) that little information was available regarding the effects of a combination of stressors (temperature and pollutants) while man performs long term submaximal work.

Methods

Nineteen healthy adult males were the subjects in this study. The young subjects were 22-26 years of age (N=10) and the older subjects were 45-55 years of age (N=9). Half of the younger subjects were smokers (N=5) and five of the older subjects were smokers, the others were nonsmokers. Table 11 presents mean data on age, height, weight, and the mean maximum aerobic power ($\dot{V}_{O_2\ max}$), determined on a walking test (4), for both age groups of subjects.

During the four hour exposures, each subject walked on a motor-driven treadmill, at a work load equivalent to approximately 35% of their individual maximal aerobic capacity ($\dot{V}_{O_2\ max}$). The subject walked for 50 minutes of

TABLE XI

The Subjects' Physical Characteristics

(Mean ± Standard Error of the Mean)

		Age (years)	Height (cm)	Weight (kg)	Area (m^2)	$\dot{V}_{O_2}$ max (ml O_2/kg·min^{-1})
Young	Smokers	23.0	179.5	73.0	1.91	42.8
	(N = 5)	0.5	2.4	8.8	0.11	2.9
	Nonsmokers	23.2	182.9	81.5	2.04	51.2
	(N = 5)	1.1	2.2	3.8	0.06	6.8
Middle-aged	Smokers	48.4	180.0	83.3	2.03	35.1
	(N = 5)	2.8	3.6	3.7	0.04	1.5
	Nonsmokers	47.0	184.6	78.1	2.01	36.4
	(N = 4)	2.5	4.4	6.1	0.09	4.0

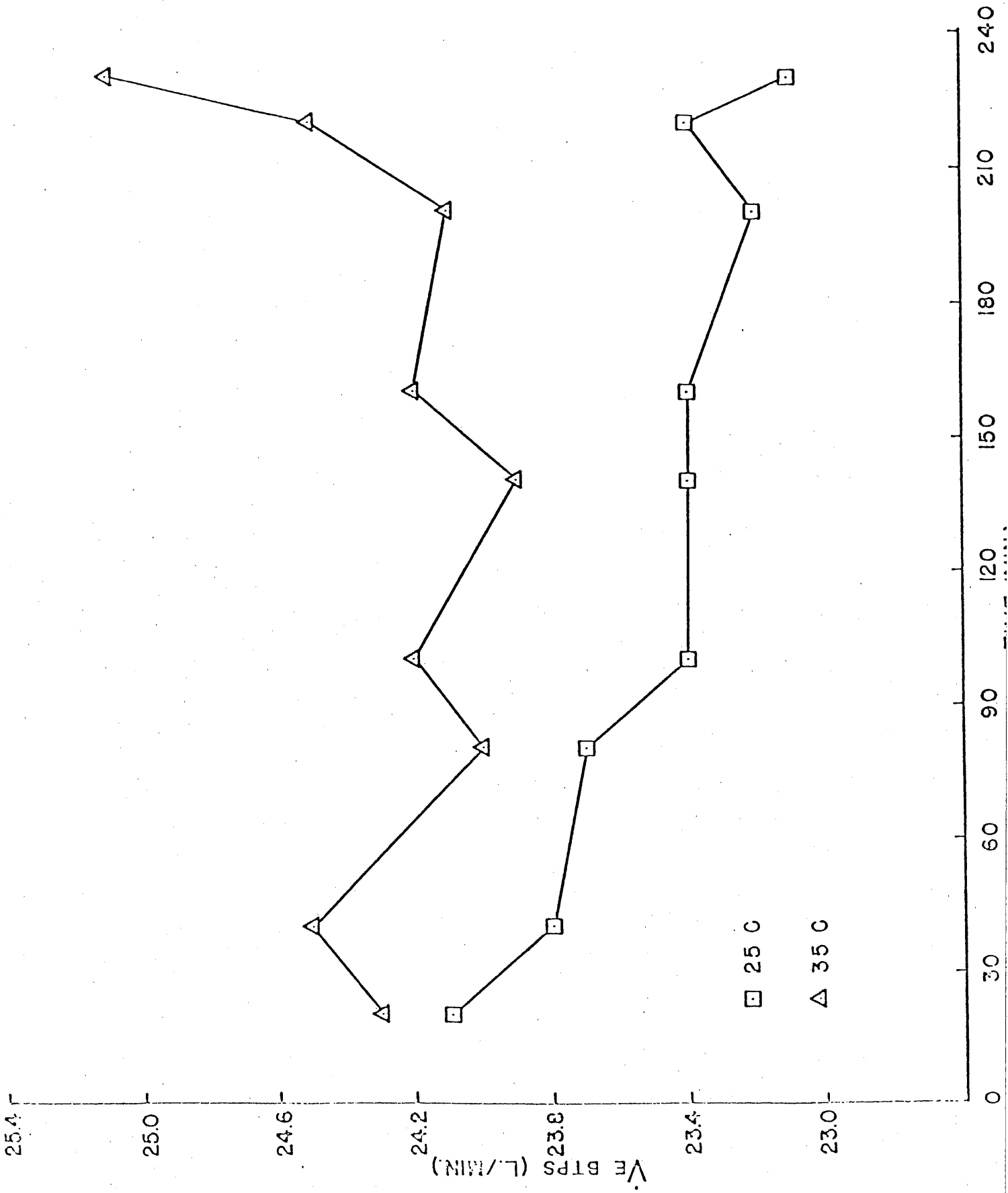
each hour and then rested for 10 minutes sitting on a stool, except in the final hour when he walked for the full 60 minutes. At 20 and 40 minutes of each hour, metabolic, temperature, and cardiovascular changes were monitored using the techniques outlined in the section on research methods. The resultant measurements allowed us to evaluate 39 distinct physiological parameters. The means and standard errors of the means of a selected number of physiological parameters are summarized for the first measurement period (20 minutes) and the last measurement period (220 minutes) of the exposure period. Tables 1 and 2, in Appendix B, present this data for young and old subjects respectively. However, the data from each 20 minute measurement session throughout exposure were analyzed utilizing a five factor analysis of variance with repeated measures for each subject across time. The factors were age, smoking habits, temperature, pollutants, and time. When a significant "F" statistic was found for the simple main effects a Newman-Keuls (5) "post hoc" test was utilized to determine those differences which were significant at the 0.05 level.

Results

Following 160 minutes of exposure significant increases in exercise ventilation occurred at 35°C compared to 25°C, regardless of age, pollutants, or smoking habits, Figure 11 ($P < 0.01$). However, there were no pollutant temperature, age or smoking effects on oxygen uptake requirements of the exercise throughout exposure ($P < 0.05$). Hence, calculation of the ventilatory equivalence ratio ($\dot{V}_E$) reflected the increased ventilation required during the latter part of the 35°C exposures and resulted in a significant increase in $\dot{V}_E$ following 200 minutes of exposure at 35°C compared to 25°C.

FIGURE XI

Ventilatory Response ($\dot{V}_E$ BTPS) at 25°C (□) and 35°C (△) Throughout the Four Hour Exposures Meaned Across Pollutant Conditions, Age, and Smoking Habits



Regardless of ambient temperature, pollutant exposure, age, or smoking habits, the rectal temperature (T_{re}) was increased at the start of the second hour significantly above that during the first hour with no further significant increase throughout the exposure (Figure 12).

However, a trend to increase from 37.8°C to 38.2°C was observed resulting in a 4 hour average T_{re} of 38.0°C. In contrast to T_{re}, the mean skin temperature ($\overline{T}_{sk}$) progressively increased throughout the exposures such that the $\overline{T}_{sk}$ was significantly greater during the final 30 minutes of exposure to 25°C than the initial 160 minutes of exposure, Figure 12 ($P < 0.05$). This progressive increase in $\overline{T}_{sk}$ was emphasized during 35°C exposures with the finding that the final 80 minutes of exposure was greater ($P < 0.05$) than the initial 60 minutes. In addition, all $\overline{T}_{sk}$ temperatures observed at 35°C were greater than those at 25°C, $P < 0.01$ (figure 12). These changes in $\overline{T}_{sk}$ resulted in similar findings for the calculated $\overline{T}_{B}$ temperature (Figure 12) and also in calculated body energy content ($P < 0.05$). As expected, 35°C exposures resulted in significantly greater total respiratory and evaporative water loss ($P < 0.01$), yet no differences were observed between smokers and nonsmokers of either age group nor were pollutants effective in changing the metabolic or temperature responses.

Figure 13 outlines the heart rate response observed throughout the exposure where differences due to temperature were meaned across pollutant conditions to demonstrate the pollutant effect. The mean CO exposure heart rates were all greater than the FA, PAN, and PANCO exposures. However, significant differences only occurred between CO and FA conditions after 160 minutes of exposure. Earlier rises in heart rate occurred when CO was present as a pollutant beginning during the second hour of

All Parameters Were Averaged Across Pollutant Conditions, Age and Smoking Habits. The Average Tre (O) Over Time for Both Ambient Temperatures and Mean Body Temperature (MBT =⊡) and Mean Skin Temperature (MST =△) at 25°C and 35°C Throughout the 4 Hour Exposures.

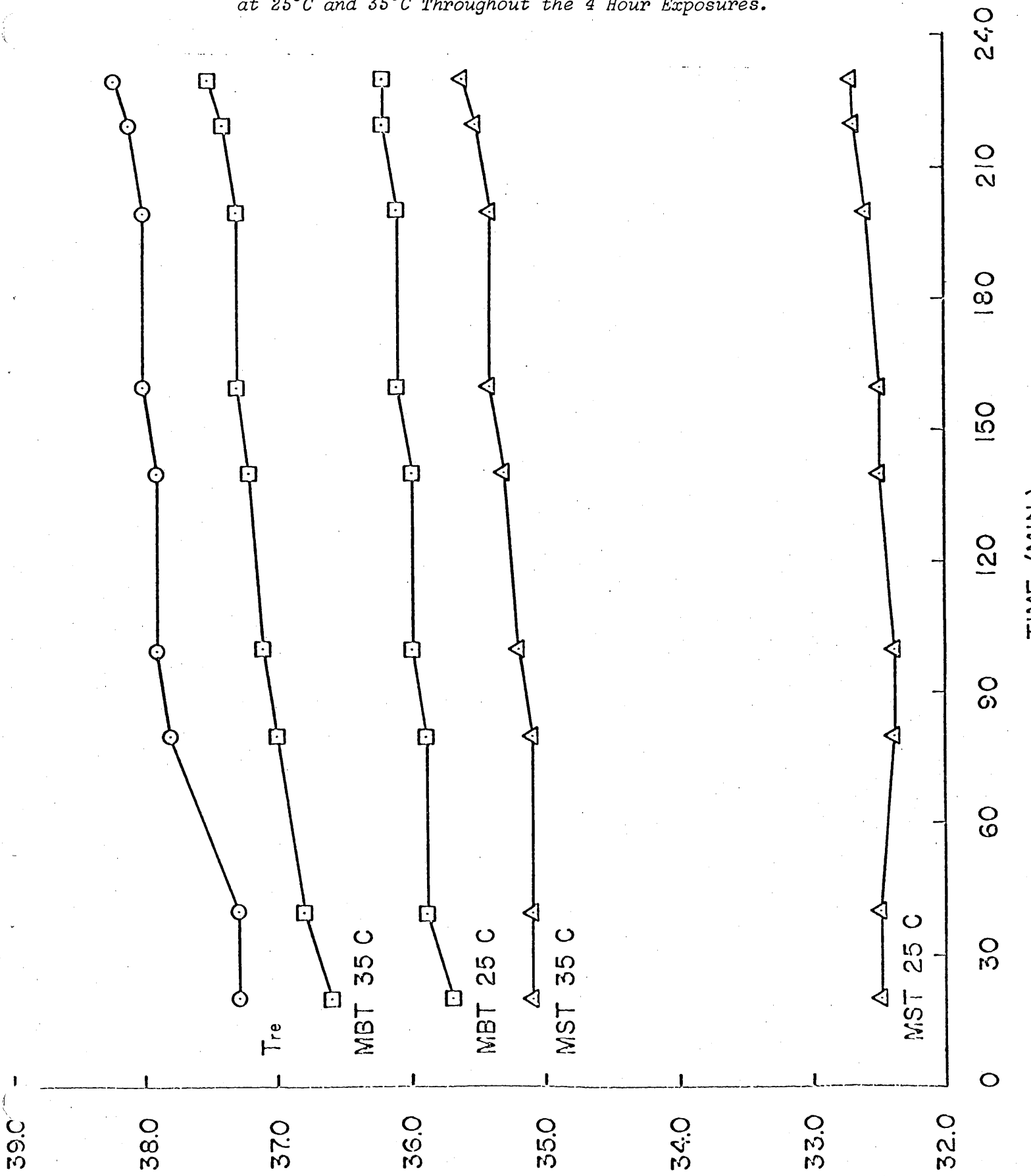
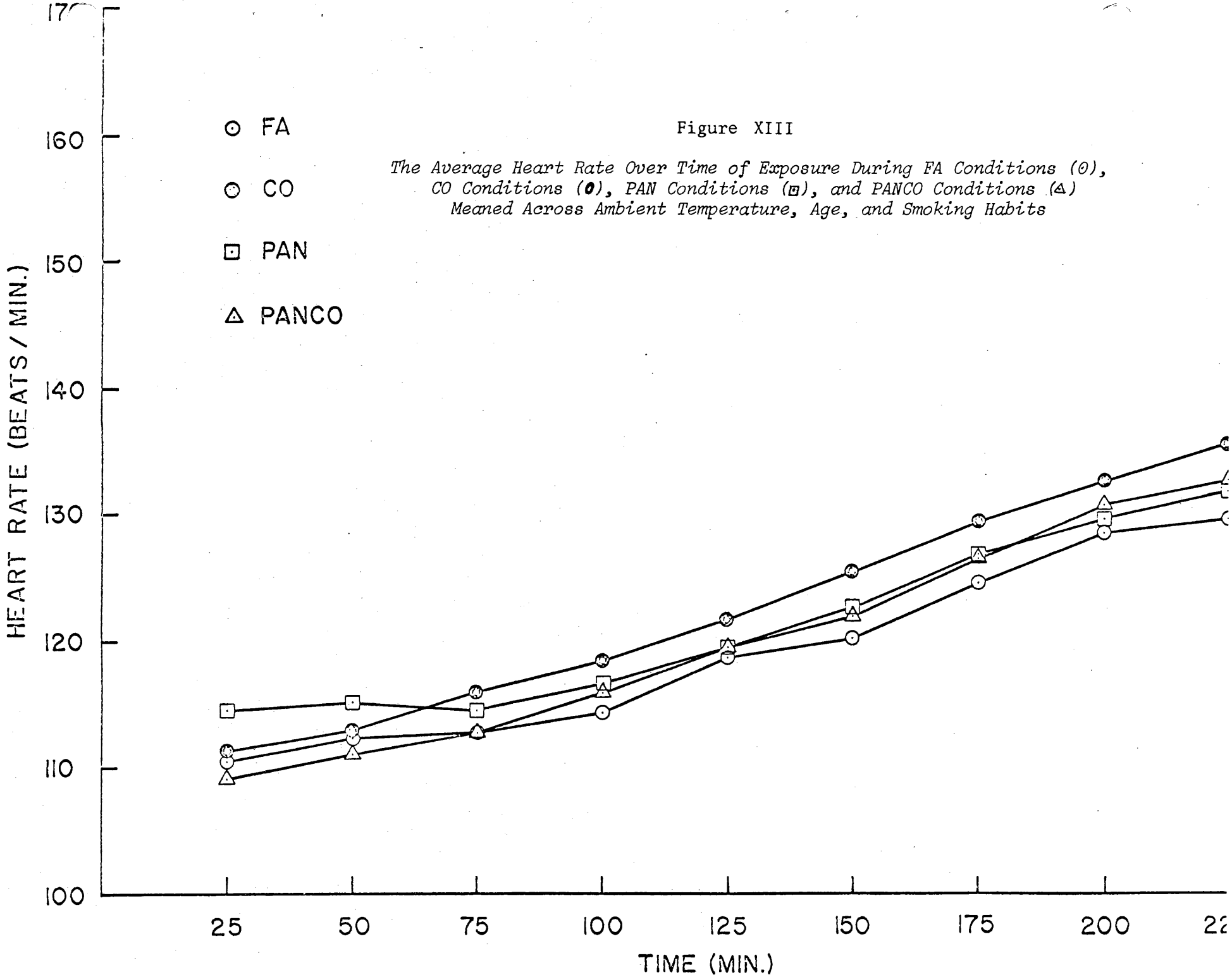


Figure XIII

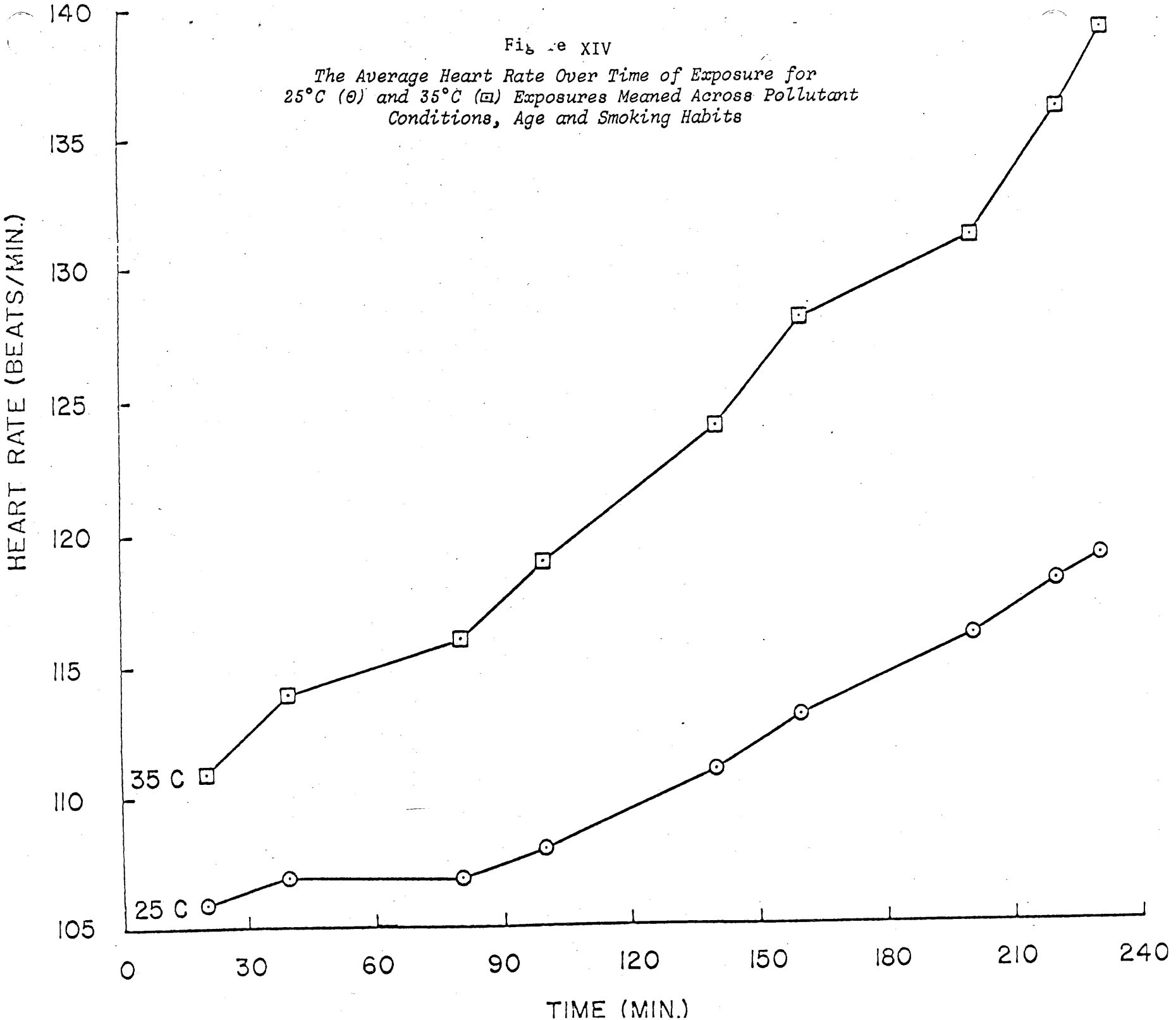
The Average Heart Rate Over Time of Exposure During FA Conditions (⊙), CO Conditions (●), PAN Conditions (⊡), and PANCO Conditions (△) Meaned Across Ambient Temperature, Age, and Smoking Habits



exposure, whereas significant increases in heart rate during FA and PAN exposure began during the third hour of exposure. All heart rates (Figure 14) during 35°C exposures were greater than during the 25°C exposures ($P < 0.01$). There were no differences in heart rate response due to smoking habits and age of the subjects ($P > 0.05$). Figure 15 summarizes the changes over time in heart rate, cardiac index, and stroke index (SI) from their first hour average for both temperatures. There were no differences in observed cardiac index (CI) over time or due to temperature, smoking habits and age ($P > 0.05$). However, during 25°C exposure no significant rise in heart rate occurred during the first two hours then a gradual increase throughout exposure was observed, reaching 11.3% above the first hour average heart rate at the end of four hours of exposure ($P < 0.01$). During 35°C significant rises in heart rate were found following the first hour of exposure, continuing throughout exposure and reaching a level of 24.2% above the first hour's average by the end of four hours of exposure ($P < 0.01$). The increases in heart rate due to time of exposure and temperature were mimicked by concomitant decreases in stroke index (Figure 15). However, there were no pollutant, age, or smoking effects in stroke index. The mean stroke index at 25°C (50.3 ml/beat·m^{-2}) was significantly greater ($P < 0.05$) than the mean stroke index during 35°C exposures (47.1 ml/beat·m^{-2}). No change in mean blood pressure or diastolic pressure was observed to occur over time or between age groups or smoking habits ($P > 0.05$). However, by the end of the first hour a significant rise in systolic pressure ($P < 0.05$) had occurred with no further change throughout exposure (Figure 16). These changes in systolic pressure occurred regardless of temperature, pollutant, age, or smoking habits. Calculated stroke work (SV x SP) indicated that the decreases in stroke volume which occurred during exposure and due to

Figure XIV

The Average Heart Rate Over Time of Exposure for 25°C (⊙) and 35°C (⊡) Exposures Meaned Across Pollutant Conditions, Age and Smoking Habits



The Average Change in Heart Rate (at 25°C O- and 35°C O- -), Stroke Index at 25°C ⊡- and 35°C ⊡- -) and Cardiac Index (Δ- Meaned for Both 25°C and 35°C) Expressed as a Percent Difference from the First Hour Average of Each Parameter

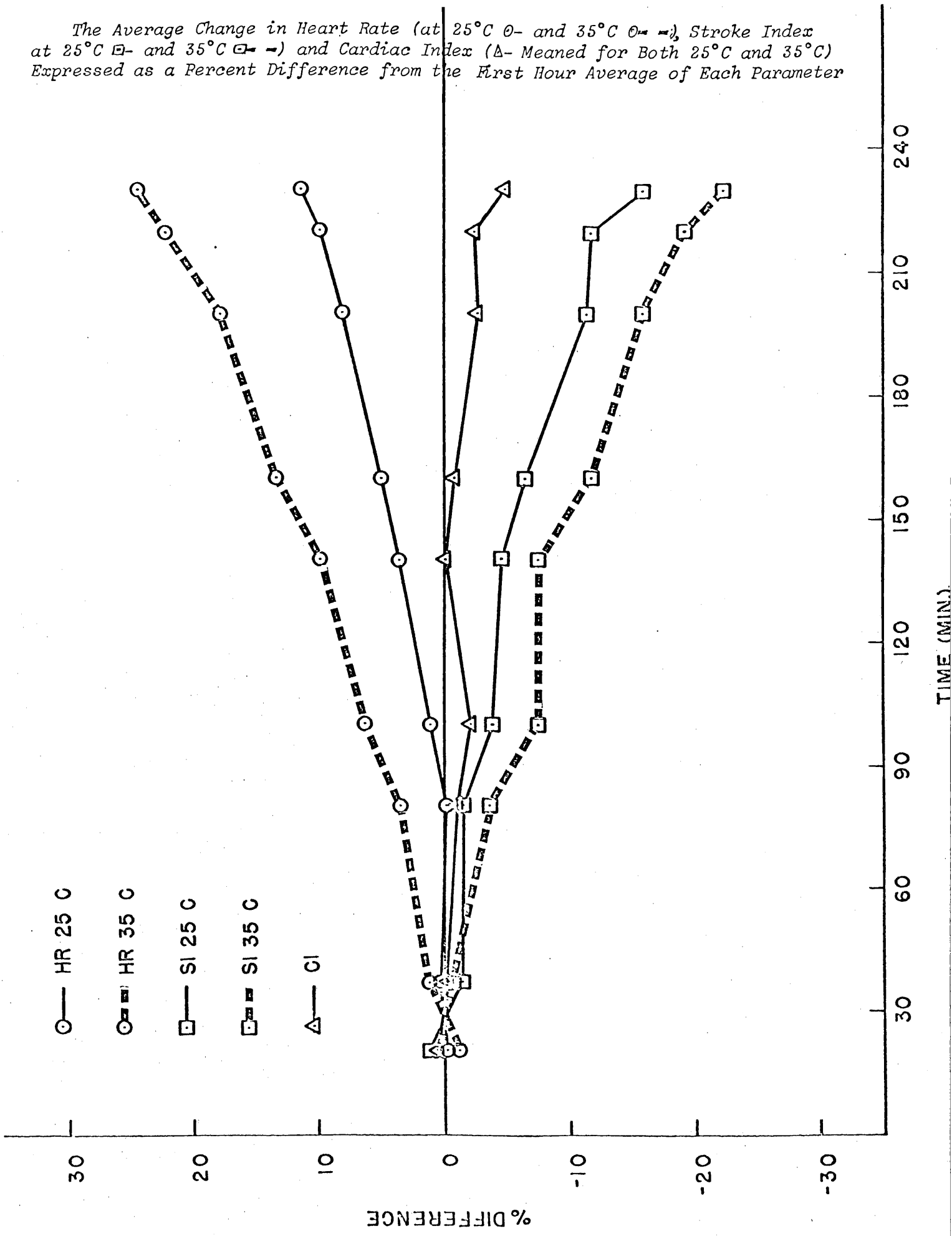
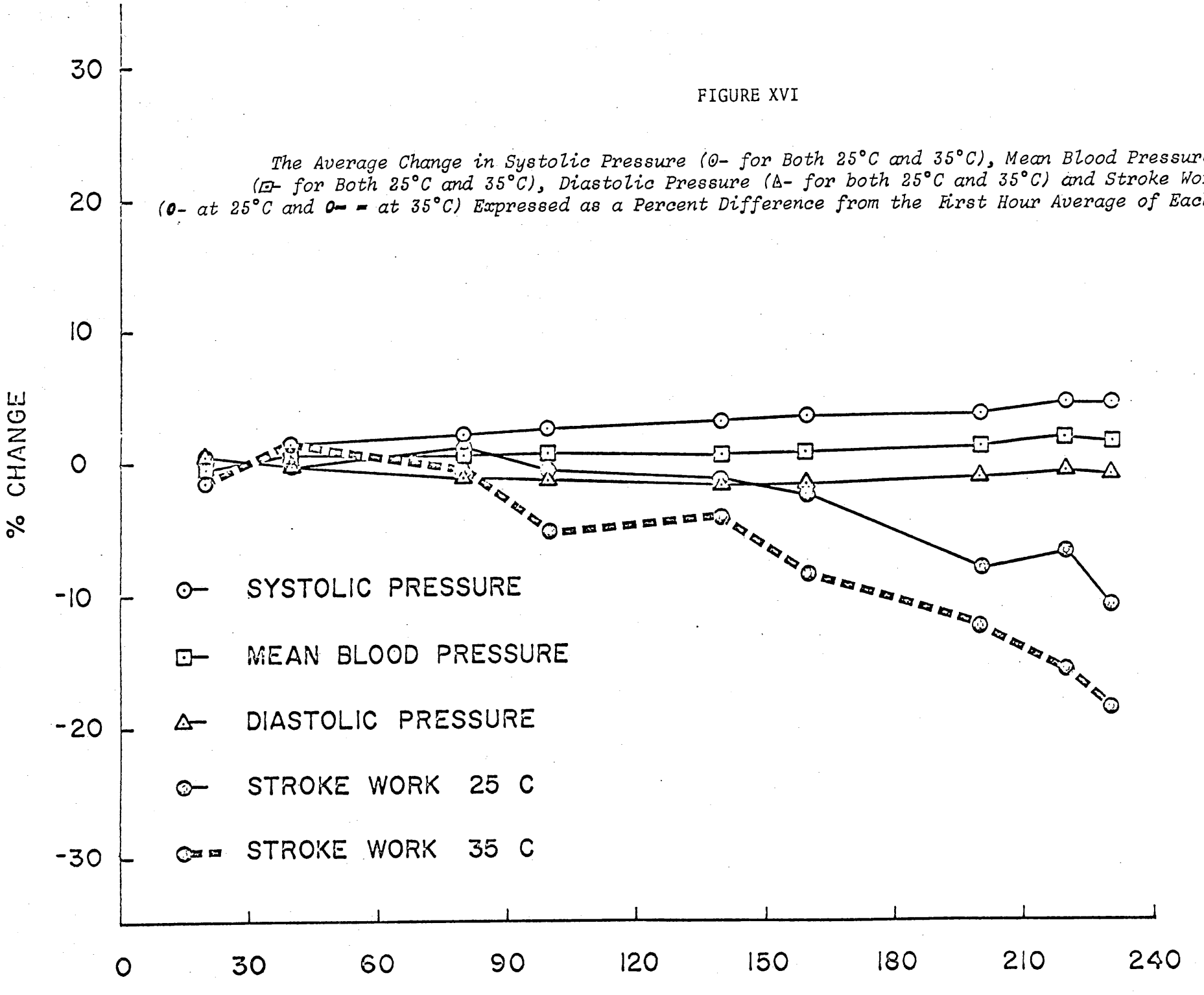


FIGURE XVI

The Average Change in Systolic Pressure (O- for Both 25°C and 35°C), Mean Blood Pressure (⊡- for Both 25°C and 35°C), Diastolic Pressure (Δ- for both 25°C and 35°C) and Stroke Work (O- at 25°C and O- - at 35°C) Expressed as a Percent Difference from the First Hour Average of Each Param



environmental temperature were large enough to overcome the rise in systolic pressure resulting in a significant decrease in stroke work during 25°C after 160 minutes of exposure and during 35°C after 140 minutes of exposure (Figure 16). Stroke work during 35°C exposures was significantly less than during 25°C exposures after 160 minutes of exposure.

Table 12 summarizes average carboxyhemoglobin levels for all groups of subjects prior to and following exposures to each of the eight conditions. Smokers ($\overline{X}$ range 2.5-5.6% COHb) had significantly greater pre values than nonsmokers ($\overline{X}$ range 0.5-0.8% COHb). Following all conditions where CO was not present as a pollutant, a significant reduction in COHb levels occurred for both smokers and nonsmokers (NS $\overline{X}$ reduction of 0.25% COHb and S $\overline{X}$ reduction of 2.6% COHb). Obviously when CO was present as a pollutant a significant addition of CO to the blood of both smokers and nonsmokers occurred resulting in COHb levels ranging from 4.6 to 5.5% for the nonsmokers and 5.4 to 6.8% for the smokers. The nonsmokers' increase in COHb levels was greater due to the exposure than the smokers' ($P < 0.01$). There was no difference in post exposure COHb levels due to temperature ($P > 0.05$). No significant differences in hemoglobin levels were found between groups, across conditions or due to exposure. However, although there was no difference between temperatures in pre hematocrit values ($P > 0.05$) resultant hematocrits following 35°C exposures (48.1%) were higher than following 25°C exposures (45.9%). Also there was a significant decrease in hematocrit following 25°C exposures (48.1% to 45.9%) but there was no change following 35°C exposures (48.1% to 48.1%). There was a significant increase ($P < 0.05$) in plasma proteins following 35°C (7.09 g to 7.52 g) exposures, yet there was no change following 25°C. Post exposure lactate levels were reduced below pre exposure lactate levels ($P < 0.01$) regardless of temperature.

TABLE XII

Mean Carboxyhemoglobin Levels (%) Prior to and Following Exposures to Both Temperatures for All Groups

		Filtered Air		Carbon Monoxide		Peroxyacetylnitrate		Carbon Monoxide Peroxyacetylnitrate		$\bar{X}$
		25	35	25	35	25	35	25	35	
Young Nonsmokers (N=5)	Pre	0.7	0.5	0.7	0.6	0.6	0.7	0.5	0.5	0.6
	Post	0.4	0.3	5.3	5.4	0.4	0.4	5.0	4.6	
Young Smokers (N=5)	Pre	4.8	4.8	5.6	4.9	4.4	4.3	4.5	5.5	4.9
	Post	1.7	1.6	6.6	6.4	1.6	1.4	6.3	6.8	
Older Nonsmokers (N=4)	Pre	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.8	0.7
	Post	0.6	0.4	5.1	4.7	0.4	0.4	5.2	5.5	
Older Smokers (N=5)	Pre	3.4	4.0	3.4	3.6	4.9	3.5	2.9	2.5	3.5
	Post	1.5	1.7	6.1	6.0	2.0	1.4	5.4	6.0	

TABLE XIII

The Four Hour Average of Selected, Metabolic, Cardiopulmonary, and Temperature Regulatory Parameter of Two Young Smokers (S) and Two Young Nonsmokers (NS)

		F.A.	50 ppm CO	75 ppm CO	100 ppm CO
$\dot{V}_{O_2}$	S	14.0	14.8	14.3	14.9
(ml O_2/kg·min^{-1})	NS	14.8	15.3	14.4	14.3
$\dot{V}_E$ BTPS	S	19.6	18.4	18.1	18.7
(1/min)	NS	28.5	29.6	27.5	26.5
VE	S	23	22	21	21
(Ratio)	NS	23	23	22	21
Cardiac Index	S	5.5	5.1	4.7	4.9
(1/min·m^{-2})	NS	5.7	6.3	6.7	6.6
Heart Rate	S	113	110	106	110
(beats/min)	NS	103	102	106	108
Rectal Temperature	S	37.8	37.6	37.5	37.6
(°C)	NS	37.9	37.9	37.9	37.9
Mean Skin Temperature	S	33.1	31.7	32.9	33.1
(°C)	NS	32.6	33.0	33.1	32.4

alter cardiorespiratory activity whereas 20% COHb did during submaximal levels of 30% $\dot{V}_{O_2\ max}$. Also Pirnay et al. (2) had found a significant rise in heart rate during moderate exercise when COHb levels reached 15%. The heart rate increase caused increased cardiac output which was thought to be a compensatory result of the decreased oxygen carrying capacity of the blood. However, their submaximal work load was greater than that utilized in the present study while their work times were considerably shorter. It would appear from the findings of the present study and the previous work (1-3) that COHb levels of 15-20% are required to elicit changes in the cardiorespiratory system above those usually experienced when work loads are below 35% $\dot{V}_{O_2\ max}$ regardless of the age or the smoking history of the healthy subject.

This does not deny that exposure to low levels of CO cannot cause changes within the cardiovascular system in a patient population. Anderson et al. (6) have showed that time to onset of angina pectoris during exercise was considerably shorter when COHb levels were 2.9 to 4.5%, also smokers were not different from nonsmokers. Aranow et al. (7) had reported similar findings in freeway drivers. Hence, it is apparent that the resultant COHb levels following four hours exposure to 50 ppm CO in the present study are within or above the range at which cardiovascular impaired individuals would be placed at greater risk than they would normally be.

The lack of change in ventilatory data as a function of COHb levels was comparable to that observed by Vogel and Gleser (3) in that metabolic requirements needed to be greater than 1.6 ℓ O_2/min oxygen uptake before $\dot{V}_{O_2}$ or $\dot{V}_E$ changes were observed. It was expected that the effects of PAN, primarily oxidant type reactions, would influence ventilatory measures. This was not the case during exercise, however, pre-post changes in vital capacity were found for the younger subjects following exposures when PAN

was present as a pollutant and are described in detail in the next section.

There is an increasing amount of information demonstrating that air pollutants can cause behavioral or performance changes without altering cardiovascular or pulmonary responses as reviewed by Horvath (8). Although the present study did not test behavioral performance as a function of air pollutants, subjects were asked to subjectively describe their feelings on a questionnaire after each session (Appendix A). The subjects complained of eye irritation, blurred vision, and eye fatigue significantly more under conditions utilizing PAN than under either filtered air or CO conditions. This supports the previous epidemiological studies (9), which found that oxidants at levels greater than 0.1 ppm produced increasing eye irritability. Also, younger subjects complained of headaches under all pollutant conditions at 35°C as compared to the filtered air condition, but there were no significant differences at 25°C while only older smokers showed a similar interaction. It is also of interest that the two nonsmokers that repeated work loads of 75 and 100 ppm complained of severe headaches whereas the 2 smokers exposed to these conditions did not. The overall physical scores suggested that PAN and PANCO conditions under 35°C produce more subjective complaints than either CO or filtered air at this temperature ($P < 0.05$). It appears that the exposure levels of CO and PAN utilized in this experiment were severe enough to cause subjective physical discomfort, but not enough to alter cardiovascular and respiratory responses.

(b) Spirometric changes following long-term work in polluted environments.

Introduction

The spirometric evaluations reported here are those determined while defining the cardiorespiratory and thermoregulatory responses of young and middle-aged adult male smokers and nonsmokers to long-term work (3.5 hours in a 4-hour exposure period), during which time they were exposed to cool (25°C) and hot (35°C) polluted environments as described previously in section IIIa.

Methods

All pulmonary function tests were performed standing upright following the standardized procedures of Kory et al. (10). Residual volumes (RV) were determined using the helium dilution technique. Exposure regimes were the same as described above (Section IIIa and Experimental Design).

Immediately prior to and following exposure, each subject performed repeat forced vital capacity tests (FVC) from maximal inspiratory capacity (IC) while standing upright. The FVC tests having the greatest magnitude of the duplicate tests prior to and following exposure were utilized for the determination of IC, expiratory reserve volume (ERV), FVC, forced expiratory volume over 1 second ($FEV_{1.0}$), and percentage of FVC ($FEV_{1.0}$/%FVC), as well as the determination of mid maximal flow rate (MMFR).

The preliminary clinical spirometric data were analyzed across age and smoking habits utilizing a two-factor factorial analysis of variance. The pre- and post-exposure FVC data were analyzed by a four-factor factorial repeated measures analysis across ambient conditions and temperatures. Where a significant interaction was observed, a Newman-Keuls "post-hoc" test of ordered means was used to determine those differences that were significant at 0.05 level (5).

Results

The average values obtained during the spirometric evaluation of the young and middle-aged subjects are summarized in Table 14. There were no differences between smokers and nonsmokers of either age group, nor were there any apparent interactive differences between age and smoking habits ($P > 0.05$). However, the older subjects had significantly greater RV and RV/%TLC than the younger subjects. In addition, the younger subjects had greater MMFR and $FEV_{1.0}$/%FVC than the older subjects. Although most of the capacity measurements were greater than the predicted normal values for age, height, and weight, the average VC, $FEV_{1.0}$, $FEV_{1.0}$/%FVC, functional residual capacity (FRC), RV, total lung capacity (TLC), and maximum breathing capacity (MBC) for each group are similar to normal values (11).

Pollutant and temperature effects were only observed in younger subjects (Table 15). Regardless of ambient temperature, the FVC of the younger subjects following PAN and PANCO exposures was significantly reduced. Furthermore, the reduction in FVC following exposures to an ambient condition containing peroxyacetylnitrate was significantly greater than that observed following filtered air conditions (mean decreases following FA = 1.8%, PAN = 3.0%, and PANCO = 5.1%; the decreases following PAN and PANCO exposures were greater than FA exposures [$P < 0.05$]). Younger subjects, regardless of smoking habits, had significant reductions in FVC (5.5%) following 35°C exposures irrespective of the ambient pollutant.

Other pulmonary parameters which were affected by exercise alone, regardless of temperature or pollutant conditions, were $FEV_{1.0}$/%FVC, ERV, and MMFR (Table 16). Both young and older subjects had significant increases in $FEV_{1.0}$/%FVC following exercise, while only young and older nonsmokers had increases in ERV. The younger subjects had a 7.3% increase in MMFR following

TABLE XIV

Results of the Clinical Spirometric Evaluation Prior to Experimental Exposures

		FVC (ml)		$FEV_{1.0}$ (ml)		$FEV_{1.0}$/%FVC (%)		IC (ml)		ERV (ml)		FRC (ml)	
		Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
NS*	$\bar{X}$	5976	5596	5168	4470	86.2	79.9	3934	3691	2014	1908	3986	4589
	$SE_{\bar{X}}$	±557	±492	±563	±402	±1.8	±1.9	±197	±491	±337	±511	±399	±486
S**	$\bar{X}$	5453	5001	4719	4074	87.3	82.2	3601	3215	1735	1554	3479	4130
	$SE_{\bar{X}}$	±572	±532	±404	±364	±3.2	±2.9	±407	±384	±237	±306	±399	±645
		no significant differences		no significant differences		older subjects were less than young. F=4.98, P < 0.05		no significant differences		no significant differences		no significant differences	

		RV (ml)		TLC (ml)		RV/%TLC (%)		MMFR (liters/sec)		MBC (liters/min)	
		Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
NS*	$\bar{X}$	1972	2680	7948	8267	25.1	32.4	6.0	4.6	191	182
	$SE_{\bar{X}}$	±310	±304	±377	±691	±4.2	±2.5	±0.7	±0.5	±17	±24
S**	X	1745	2576	7197	7577	24.3	34.0	5.4	4.4	157	159
	$SE_{\bar{X}}$	±202	±351	±697	±798	±1.8	±2.9	±0.6	±0.6	±18	±22
		Older subjects had larger RV than young F=8.40; P < 0.05		no significant differences		Older subjects were greater than young F=9.5; P < 0.01		Older subjects were lower than young F=4.5; P < 0.05		no significant differences	

*Nonsmokers
**Smokers

TABLE XV

*Forced Vital Capacity Determinations Following Exposures To Pollutants and Temperatures of Young Smokers and Nonsmokers**

	Pre (ml)	Post (ml)	Δ (%)	P
PAN	5618	5379	-4.3	<0.05
PANCO	5676	5264	-7.3	<0.01
25°C	5650	5505	-2.6	NS
35°C	5633	5325	-5.5	<0.01

*There were no significant differences between smokers and nonsmokers nor were there any pollutant or temperature effects for the older subjects.

TABLE XVI

Changes in Other Pulmonary Parameters Following Exercise*

Parameter	Subjects	Pre	Post	Δ(%)	P
$FEV_{1.0}$/%FVC (%)	Young	86.1	88.6	+2.9	<0.01
	Old	80.4	82.0	+2.0	<0.05
ERV (ml)	Young Nonsmokers	1874	2043	+9.0	<0.05
	Older Nonsmokers	1854.5	1908.8	+2.9	<0.05
MMFR (liters/sec)	Young	5.46	5.86	+7.3	<0.01

*These changes were those observed following exercise with temperature and pollutant conditions grouped together because the conditions produced no discrete effect on these parameters

exercise. There were no significant interactions between pollutants, temperature, exercise, or smoking habits.

Discussion

The FVC of younger subjects was reduced 4-7% following 4 hours of exposure to PAN, yet the FVC of older subjects was unaffected, suggesting an age-related susceptibility to PAN. An age-related susceptibility to another oxidant pollutant, ozone (O_3), has been demonstrated by Stokinger (12), who reported that younger mice were more susceptible to O_3 toxicity than were older mice. However, in the present study we have found that this susceptibility involves a functional component of life. It is doubtful that a decreased dosage of pollutant to the older subjects occurred as a result of their larger RV, as equilibration of FRC would have occurred within 10 or 15 minutes of exposure. Possible factors involved in the changed FVC are those that primarily influence distribution of ventilation, such as regional differences in intrapleural pressure, changes in mechanical properties of various parallel pathways of the lung, and changes in airway closure (11). As pleural pressure in dependent lung zones exceeds airway pressure, airway closure ensues (13, 14), thereby limiting expiration from dependent lung zones (14, 15). It has been shown that increases in RV of older subjects compared with younger subjects are due to greater airway closure at higher lung volumes, suggesting that younger subjects do not attain minimal volume in the upper regions of the lung (11, 16). In the present study, it can be assumed that the reduction in FVC was primarily a result of increasing RV, as there was no change in IC. This increased RV was probably a result of early airway closure in the dependent lung zones. An explanation for the age differences in susceptibility to oxidants may be related to the fact that the dependent regions of the lung of the older subjects were closing at higher

lung volumes prior to exposure (Table 14) and that the oxidant pollutants produce changes in lung tissue that mimic these age-related changes. Therefore, the areas of the lung primarily affected by the oxidant will have already undergone these age-related changes in the older subjects and will not be responsive to oxidant irritation. It could be hypothesized that PAN affects ventilation distribution in the dependent zones of the lung by either decreasing airway pressure or increasing pleural pressure of these regions at a given lung volume. Whether a similar explanation can be used to describe the decreased FVC following 35°C exposure is questionable, although it raises the possibility that thermal stress may change dependent lung zone ventilation.

In this study, we have described changes in a simple spirometric evaluation of lung function of younger and older subjects following exposure to an oxidant-type pollutant. Whether these alterations in function reported here would have consequences to human health is questionable. However, the may be indicative of the dose level of PAN required to initiate changes in physiological function. The implication of an age-related susceptibility to oxidant pollutants is of particular importance in view of the fact that proposed emission control standards will actually cause raised levels of ambient oxidant.

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*These publications resulted in whole or in part from the research supported by this grant from the Air Resources Board.

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(1) RESPIRATORY MEASUREMENTS

Parameter and Formula	Abbreviation	Units
1. Ventilatory Volume		
(a) $\dot{V}_E$ (uncorrected volume)	$\dot{V}_E$	liters/min
(b) $\dot{V}_E$ BTPS = $\dot{V}_E \times \frac{310}{273 + \text{gas temp.}} \times \frac{BP - WVP}{BP - 47}$	$\dot{V}_E$ BTPS	liters/min
(c) $\dot{V}_E$ STPD = $\dot{V}_E \times \frac{BP - WVP}{760} \times \frac{273}{273 + \text{gas temp.}}$	$\dot{V}_E$ STPD	liters/min
	BP = barometric pressure	
	WVP = water vapor pressure at the gas temperature	
2. Respiratory Rate	RR or f	breaths/min
3. Tidal Volume		
$\frac{\dot{V}_E}{RR}$	TV	mls/breath
4. Ventilatory Equivalence Ratio		
$\frac{\dot{V}_E \text{ BTPS}}{\text{Oxygen Uptake}}$	$\dot{V}_E$ BTPS/$\dot{V}_{O_2}$	$\frac{\text{liters breath}}{\text{liters } O_2}$

(2) METABOLIC MEASUREMENTS

Parameter and Formula	Abbreviation	Units
1. Oxygen Uptake		
(a) $\frac{\dot{V}_E \text{ STPD} \times \text{True } O_2\%}{100}$	$\dot{V}_{O_2}$	liters O_2/min
(b) $\frac{\dot{V}_E \text{ STPD} \times \text{True } O_2\% \times 1000}{100 \times \text{Pre Wt}}$	$\dot{V}_{O_2}$	ml O_2/kg·min^{-1}
(c) $\frac{\dot{V}_E \text{ STPD} \times \text{True } O_2\% \times 1000}{100 \times \text{Lean Body Mass}}$	$\dot{V}_{O_2}$	ml O_2/LBM·min^{-1}
2. True Oxygen		
$(\%N_2 \times 0.265) - \%O_2$ in expired air	True O_2	%
3. Respiratory Exchange Ratio	R	no units
$\frac{\%\text{ Expired } CO_2}{\%\text{ Inspired } O_2}$ or $\frac{CO_2 \text{ Production}}{\text{Oxygen Uptake}}$	$\frac{\dot{V}_E\ CO_2}{\dot{V}_{O_2}}$	
4. Excess Carbon Dioxide	Excess CO_2	liters
$\dot{V}_E \text{ STPD} \times \frac{(\%CO_2 \text{ Expired} - 0.03)}{100} - \dot{V}_{O_2} \times 0.75$		
5. Maximal Aerobic Power	$\dot{V}_{O_2\ max}$	liters/min
and/or		ml O_2/kg·min^{-1}
Maximal Aerobic Capacity		ml O_2/LBM·min^{-1}
(The largest value of oxygen uptake obtained when a subject performs maximal exhaustive work.)		

Parameter and Formula	Abbreviation	Units
6. Percent of Maximal Oxygen Uptake	$\%\dot{V}_{O_2\ max}$	%

$$\frac{\dot{V}_{O_2}}{\dot{V}_{O_2\ max}} \times 100$$

7. Energy Production

cal/liter O_2 = 1.27604 x R + 3.82041

(a) = cal/liter O_2 x 60 x liter O_2/min	M	kcal/hr
(b) = $\frac{a}{\text{Pre Wt, in kg}}$	M	$kcal/kg \cdot hr^{-1}$
(c) = $\frac{a}{BSA}$	M	$kcal/m^2 \cdot hr^{-1}$
(d) = c x 1.163	M	$watts/m^2$

(3) CARDIOVASCULAR

1. Cardiac Output = Stroke Volume x HR	$\dot{Q}$	liters/min

$$\frac{\dot{V}_{O_2}}{Ca_{O_2} - C_{v_{O_2}}}$$

2. Cardiac Index	CI	$liters/min \cdot m^{-2}$

$$\frac{\dot{Q}}{\text{Body Surface Area, in } m^2}$$

Body Surface Area = BSA

Parameter and Formula	Abbreviation	Units
3. Cardiac Work $\frac{SP \times 13.6 \times \dot{Q}}{1000}$	CW	kg·m/min
4. Heart Rate	HR, f	beats/min
5. Stroke Volume $\frac{\dot{Q}}{HR}$	SV	ml/beat
6. Stroke Index $\frac{SV}{BSA}$	SI	ml/beat·m^{-2}
7. Stroke Work $\frac{SP \times 13.6 \times SV}{1000}$	SW	gm.m/beat
8. Oxygen Pulse $\frac{\dot{V}_{O_2} \times 1000}{HR}$	O_2 Pulse	ml O_2/beat of the heart

Parameter and Formula	Abbreviation	Units
9. Arteriovenous Oxygen Difference $\frac{\dot{V}_{O_2} \times 1000}{\dot{Q}}$	A - VO_2 diff. (a - v)O_2 diff.	ml O_2/liter blood
10. Systolic Pressure (arterial)	SP	mm Hg
11. Diastolic Pressure (arterial)	DP	mm Hg
12. Mean Blood Pressure (arterial) $\frac{SP - DP}{3} + DP$	MBP	mm Hg
13. Pulse Pressure $SP - DP$	PP	mm Hg
14. Total Peripheral Resistance $\frac{1.333 \times 60 \times MBP}{\dot{Q}}$	TPR	dynes·sec cm^{-5}

(4) PULMONARY

1. Forced Vital Capacity	FVC	(ml, ml/kg) ml/m^2

Parameter and Formula	Abbreviation	Units
2. Timed Forced Expired Volumes (1.0, 2.0, and 3.0 seconds)	$FEV_{1.0}$ $FEV_{2.0}$ $FEV_{3.0}$	ml
3. Forced Expired Volumes as a percentage of Forced Vital Capacity $\frac{FEV_{1.0}}{FVC} \times 100$	$FEV_{1.0}/\%FVC$ $FEV_{2.0}/\%FVC$ $FEV_{3.0}/\%FVC$	%
4. Inspired Capacity	IC	ml
5. Expiratory Reserve Volume	ERV	ml
6. Functional Residual Volume	FRC	ml
7. Residual Volume	RV	ml, ml/kg, ml/m^2
8. Total Lung Capacity VC + RV	TLC	ml, ml/kg, ml/m^2
9. Residual Volume/Percent Total Lung Capacity $\frac{RV}{TLC} \times 100$	RV/%TLC	%
10. Mid-Maximal Flow Rate	MMFR	l/sec

Parameter and Formula	Abbreviation	Units
11. Maximal Breathing Capacity	MBC	liters/min

(5) HEMATOLOGIC

1. Hemoglobin	Hb	mMoles/liter, gm %
2. Hematocrit	Hct	%
3. Plasma Proteins		gm %
4. Lactate	HLa	mEq/liter
5. Carboxyhemoglobin	COHb	%, vols %

$$\frac{\text{COHb (vols \%)}}{\text{Hb (gm \%) x 1.39}} \times 100$$

(6) TEMPERATURE REGULATORY

1. Rectal Temperature	T_{re}	°C
2. Forehead Temperature	T_{hd}	°C
3. Arm Temperature	T_{arm}	°C
4. Finger Temperature	T_{fing}	°C
5. Thigh Temperature	T_{thi}	°C
6. Calf Temperature	T_{calf}	°C

Parameter and Formula	Abbreviation	Units
7. Chest Temperature	T_{ch}	°C
8. Toe Temperature	T_{toe}	°C
9. Room Temperature	T_{room}	°C
10. Radiant Temperature	T_{rad}	°C
11. Wall Temperature	T_{wall}	°C
12. Mean Skin Temperature	$\overline{T}_{SK}$	°C

$$\overline{T}_{SK} = 0.07\ T_{hd} + 0.36\ T_{ch} + 0.05\ T_{fing} + 0.14\ T_{arm} + 0.05\ T_{toe} + 0.13\ T_{calf} + 0.20\ T_{thi}$$

13. Mean Body Temperature	$\overline{T}_B$	°C

$$0.65\ T_{re} + 0.35\ \overline{T}_{SK}$$

14. Body Heat Content	BHC	$kcal/m^2$

$$\frac{\text{Pre Wt} \times 0.83\ \overline{T}_B}{\text{BSA}}$$

15. Tissue Conductance	K	$kcal/m^2 \cdot hr^{-1} \cdot °C^{-1}$

$$\frac{kcal/m^2 \cdot hr^{-1}}{T_{re} - \overline{T}_{SK}} = \frac{\text{Energy Prod}}{T_{re} - \overline{T}_{SK}}$$

16. Respiratory Evaporative Water Loss	Resp H_2O Loss	gm/hr

$\dot{V}_E$ BTPS x factor x 60

(The factor is determined from density steam tables and is dependent on temp. of expired gases.)

Parameter and Formula	Abbreviation	Units
17. Respiratory Evaporative Heat Loss	Resp Heat Loss	$kcal/m^2 \cdot hr^{-1}$

$$\frac{\text{Resp } H_2O \text{ Loss} \times 0.58}{\text{BSA}}$$

18. Skin Evaporative Heat Loss	Evap Heat Loss	$kcal/m^2 \cdot hr^{-1}$

$$\frac{[\text{Pre Wt} - \text{Post Wt} - \text{Resp } H_2O \text{ Loss} - \text{Excess } CO_2 \text{ (gm)}] \times 0.580}{\text{BSA}}$$

APPENDIX A

APPENDIX A

General Questionnaire Used in Air Pollution Investigation

Instructions: You are to put a circle around the number which best describes how you feel right at this moment. Put down what first comes into your mind. Don't try to analyze too closely.

Name_____ Date_____ Time_____

1.	a. very drowsy	b. a little drowsy	c. about average drowsiness	d. less drowsy than usual	e. not drowsy at all
2.	a. severly nauseated	b. quite nauseated	c. some nausea	d. a little nauseated	e. not nauseated at a
3.	a. very pleased	b. a little pleased	c. about average pleased	d. less pleased than usual	e. not pleased at all
4.	a. very lively	b. a little lively	c. about average liveliness	d. less lively than usual	e. not lively at all
5.	a. severly short of breath	b. quite short of breath	c. some shortness of breath	d. a little short of breath	e. not short of breat at all
6.	a. severly dizzy	b. quite dizzy	c. some dizziness	d. a little dizzy	e. not dizzy at all
7.	a. very happy	b. a little happy	c. about average happiness	d. less happy than usual	e. not happy at all
8.	a. very tired	b. a little tired	c. about average tiredness	d. less tired than usual	e. not tired at all
9.	a. very irritable	b. a little irritable	c. about average irritability	d. less irritable than usual	e. not irritable at a
10.	a. feel hot	b. quite warm	c. slightly warm	d. hardly warm	e. not warm at all
11.	a. very active	b. a little active	c. about usual activity	d. less active than usual	e. not active at all
12.	a. very satisfied	b. a little satisfied	c. about usual satisfaction	d. less satisfied than usual	e. not satisfied at a
13.	a. very dry nose	b. badly dry nose	c. some dryness in the nose	d. a little dryness in the nose	e. no dryness in the nose at all

14.	a. very lazy	b. a little lazy	c. about usual laziness	d. less lazy than usual	e. not lazy at all
15.	a. very comfortable	b. a little comfortable	c. about usual comfort	d. less comfortable than usual	e. not comfortable at all
16.	a. very sleepy	b. a little sleepy	c. about usual sleepiness	d. less sleepy than usual	e. not sleepy at all
17.	a. very anxious	b. quite anxious	c. moderately anxious	d. a little anxious	e. not anxious at all
18.	a. severe earache	b. bad earache	c. some earache	d. a little earache	e. no earache
19.	a. severe blurring of vision	b. bad visual blurring	c. some difficulty in seeing	d. slight difficulty in seeing	e. clear vision
20.	a. very depressed	b. a little depressed	c. about usual depression	d. less depressed than usual	e. not depressed at al
21.	a. very energetic	b. a little energetic	c. about usual energy	d. less energy than usual	e. not energetic at al
22.	a. severe cramping	b. bad cramping	c. some cramping	d. a little cramping	e. no cramping at all
23.	a. very refreshed	b. a little refreshed	c. about usual refreshed	d. less refreshed than usual	e. not refreshed at al
24.	a. very vigorous	b. a little vigorous	c. about usual vigor	d. less vigorous than usual	e. not vigorous at all
25.	Last night I slept: a. very well	b. quite well	c. about average	d. not very well	e. hardly at all
26.	a. very hungry	b. a little hungry	c. about usual hunger	d. less hungry than usual	e. not hungry at all
27.	a. eyes are very tired	b. eyes are quite tired	c. eyes are some tired	d. eyes are a little tired	e. eyes are not tired at all
28.	a. very thirsty	b. quite thirsty	c. slightly thirsty	d. a little thirsty	e. not thirsty at all
29.	a. severe headache	b. bad headache	c. some headache	d. a little headache	e. no headache at all
30.	a. feel very cold	b. quite cold	c. slightly cold	d. chilly	e. not cold at all
31.	a. very confident	b. quite confident	c. moderately confident	d. a little confident	e. not confident at all
32.	a. severe heart pounding	b. bad heart pounding	c. some heart pounding	d. a little heart pounding	e. no heart pounding at all
33.	a. very dry mouth	b. dry mouth	c. some dryness of mouth	d. mouth a little dry	e. no dryness of mout

APPENDIX B

Table 2 - *Selected Parameters During the First Hour and Fourth Hour of the Work Exposures of the Older Subjects. (Means and Standard Error of the Means).*

		Filtered Air Exposure						50 ppm Carbon Monoxide					
		25°C			35°C			25°C			35°C		
	Group	Begin	4th hr		Begin	4th hr		Begin	4th hr		Begin	4th hr	
Oxygen uptake ($ml\ O_2/kg \cdot min^{-1}$)	NS	13.0 (1.6)	12.9 (1.8)		13.6 (1.6)	14.0 (2.3)		13.9 (1.7)	13.1 (1.8)		13.4 (1.9)	14.1 (1.7)	
	S	12.2 (0.6)	12.3 (0.7)		12.0 (0.7)	12.0 (0.5)		11.7 (0.8)	11.5 (1.0)		11.9 (0.9)	12.8 (1.0)	
Ventilatory volume (l/min)	NS	22.5 (1.8)	21.6 (2.2)		24.7 (3.2)	25.2 (4.9)		23.7 (1.8)	20.8 (2.5)		23.7 (3.2)	25.4 (3.2)	
	S	23.6 (1.8)	23.1 (1.6)		22.9 (1.7)	24.2 (2.0)		23.4 (2.1)	22.8 (2.1)		22.4 (2.6)	25.6 (2.7)	
Resp. exchange ratio (R)	NS	0.82 (0.03)	0.75 (0.01)		0.83 (0.05)	0.75 (0.02)		0.79 (0.05)	0.72 (0.03)		0.83 (0.05)	0.75 (0.02)	
	S	0.80 (0.02)	0.72 (0.04)		0.83 (0.01)	0.78 (0.03)		0.83 (0.02)	0.74 (0.06)		0.82 (0.02)	0.76 (0.01)	
Cardiac output (l/min)	NS	10.6 (0.5)	10.9 (1.1)		9.7 (0.4)	11.4 (0.7)		10.1 (1.1)	9.7 (0.6)		10.5 (1.5)	10.3 (2.0)	
	S	12.4 (1.9)	12.8 (1.5)		11.7 (0.9)	12.0 (0.4)		12.1 (1.2)	12.6 (1.3)		11.2 (0.8)	11.8 (1.3)	
Heart rate (beats/min)	NS	102 (3)	114 (6)		106 (3)	131 (9)		106 (4)	121 (6)		104 (4)	140 (4)	
	S	106 (5)	115 (7)		114 (4)	134 (6)		111 (5)	125 (9)		117 (4)	144 (8)	
Stroke volume (mls/beat)	NS	100.0 (9.0)	90.6 (9.0)		88.0 (9.3)	85.2 (10.2)		90.0 (9.6)	77.7 (10.6)		98.6 (14.0)	77.0 (17.8)	
	S	123.2 (17.3)	115.8 (17.1)		104.5 (5.6)	84.4 (3.9)		112.3 (18.7)	104.2 (4.7)		94.9 (8.3)	83.7 (11.5)	
Mean blood pressure (mmHg)	NS	93.3 (9.4)	99.6 (8.6)		89.8 (7.9)	95.6 (11.7)		96.7 (7.9)	106.8 (10.7)		89.3 (5.4)	95.6 (5.0)	
	S	94.5 (3.6)	100.3 (6.4)		98.3 (3.2)	101.8 (4.8)		96.8 (8.1)	100.3 (12.0)		96.7 (4.3)	101.3 (2.8)	
Total per. resist. ($dynes \cdot sec/cm^5$)	NS	713 (107)	736 (67)		739 (38)	671 (59)		775 (75)	878 (31)		690 (65)	779 (168)	
	S	642 (110)	656 (115)		683 (57)	679 (39)		656 (86)	636 (46)		700 (51)	701 (61)	
Rectal temperature (°C)	NS	37.0 (0.3)	38.1 (0.1)		37.2 (0.1)	38.5 (0.2)		37.2 (0.1)	38.0 (0.1)		37.3 (0.1)	38.6 (0.2)	
	S	37.4 (0.1)	38.0 (0.1)		37.4 (0.2)	38.2 (0.1)		37.4 (0.1)	38.0 (0.1)		37.4 (0.2)	38.3 (0.2)	
Mean skin temperature (°C)	NS	32.7 (0.5)	33.0 (0.5)		35.4 (0.2)	35.7 (0.4)		32.4 (0.6)	32.2 (0.4)		35.2 (0.2)	35.4 (0.3)	
	S	32.3 (0.4)	32.3 (0.6)		34.9 (0.2)	35.2 (0.4)		32.6 (0.3)	33.1 (0.4)		35.3 (0.3)	35.6 (0.5)	
Tissue conductance ($Kcal/m^2 \cdot hr\ °C$)	NS	36.1 (7.0)	28.0 (4.2)		85.3 (10.1)	58.4 (7.3)		30.8 (1.5)	23.5 (1.4)		72.4 (8.9)	49.0 (2.8)	
	S	28.9 (1.7)	25.7 (1.8)		58.7 (7.4)	51.0 (7.3)		29.1 (2.7)	27.9 (3.1)		72.2 (8.0)	58.7 (8.1)	

0.27 ppm Peroxyacetylnitrate

50 ppm CO and 0.27 ppm PAN

25°C				35°C				25°C				35°C			
Begin		4th hr		Begin		4th hr		Begin		4th hr		Begin		4th hr	
13.4	(1.4)	13.0	(1.5)	13.2	(1.6)	13.2	(2.0)	14.2	(1.2)	14.3	(1.3)	13.5	(1.5)	14.0	(1.9)
12.0	(0.5)	12.3	(0.6)	12.7	(0.7)	12.8	(0.6)	11.9	(0.7)	12.0	(0.9)	12.2	(0.6)	12.4	(0.9)
23.6	(3.1)	22.5	(4.1)	23.1	(2.5)	23.2	(4.6)	24.8	(2.4)	25.2	(2.8)	23.6	(2.6)	23.6	(2.9)
24.3	(2.0)	23.7	(2.5)	24.5	(2.0)	24.6	(2.4)	23.8	(1.7)	22.9	(2.0)	23.8	(1.6)	23.4	(3.0)
0.82	(0.04)	0.75	(0.02)	0.83	(0.05)	0.76	(0.02)	0.83	(0.03)	0.76	(0.03)	0.82	(0.03)	0.74	(0.01)
0.85	(0.03)	0.78	(0.02)	0.81	(0.03)	0.72	(0.01)	0.85	(0.03)	0.76	(0.02)	0.81	(0.03)	0.76	(0.02)
10.3	(1.4)	9.3	(2.0)	11.5	(2.7)	10.5	(2.5)	10.2	(0.4)	10.8	(1.9)	10.4	(0.7)	11.0	(1.3)
12.0	(1.1)	11.2	(1.1)	12.8	(1.5)	12.2	(1.0)	12.8	(0.7)	12.4	(1.0)	13.2	(1.1)	12.4	(1.8)
101	(4)	108	(6)	110	(3)	136	(7)	105	(3)	119	(9)	106	(5)	138	(6)
108	(3)	117	(2)	114	(5)	136	(6)	107	(5)	119	(8)	110	(5)	135	(7)
101.3	(13.6)	82.4	(20.8)	101.0	(25.7)	77.6	(24.1)	95.6	(5.7)	87.3	(20.0)	96.9	(10.1)	84.3	(13.6)
112.1	(13.6)	97.1	(10.4)	115.9	(17.2)	92.6	(10.6)	119.7	(12.7)	109.1	(11.2)	121.5	(12.8)	90.7	(15.0)
94.0	(9.1)	91.3	(8.0)	91.8	(5.7)	95.1	(15.4)	98.9	(5.5)	95.8	(8.0)	95.3	(7.7)	91.7	(10.3)
97.6	(6.5)	100.6	(5.2)	99.7	(5.4)	101.5	(4.2)	97.3	(7.6)	101.8	(9.2)	100.0	(8.3)	101.0	(11.0)
738	(49)	811	(103)	673	(112)	761	(142)	775	(33)	729	(88)	737	(66)	674	(87)
663	(60)	741	(93)	639	(68)	674	(57)	616	(64)	664	(81)	619	(83)	682	(119)
37.0	(0.1)	37.8	(0.1)	37.2	(0.2)	38.4	(0.3)	37.2	(0.0)	37.8	(0.1)	37.1	(0.1)	38.2	(0.2)
37.5	(0.2)	38.1	(0.2)	37.3	(0.1)	38.1	(0.1)	37.4	(0.1)	38.0	(0.2)	37.4	(0.1)	38.2	(0.2)
32.0	(0.5)	32.6	(0.2)	34.8	(0.4)	35.0	(0.5)	32.8	(0.7)	32.7	(0.5)	35.2	(0.3)	35.4	(0.6)
32.9	(0.5)	32.9	(0.6)	34.7	(0.3)	35.5	(0.4)	32.8	(0.4)	33.4	(0.3)	34.8	(0.5)	35.1	(0.5)
31.5	(4.8)	29.3	(3.8)	65.4	(11.5)	42.6	(5.9)	38.5	(5.9)	32.0	(5.2)	87.3	(23.3)	56.4	(8.8)
32.6	(3.7)	27.5	(4.1)	59.1	(5.2)	62.2	(10.6)	31.3	(2.1)	31.1	(1.6)	62.2	(10.5)	51.6	(9.6)