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PREDICTION OF THERMAL STRESS CASUALTIES

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Young adult male subjects (n=15) were monitored under conditions featuring various combinations of three factors: work (rest or treadmill walking at 50% V_{O_2}, clothing (USAF flight) suit or USAF flight suit plus the MOPP-IV chemical defense ensemble (CDE)), and environment (in an air-conditioned laboratory or outside in the desert summer). Biogenic amine and metabolite responses were determined from timed urine samples using the high performance liquid chromatography (HPLC) with electrochemical detection. The response profiles of subjects (n=9) able to persist in their exercise while wearing CDE outdoors in the heat were compared with those (n=6) unable to persist (those who voluntarily terminated exercise at 50% V_{O_2} max before they had worked for 30 min or reached a rectal temperature of 38.5 °C (101.3 °F)).

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19. ABSTRACT (Continued)

The data support the conclusion that subjects who persisted in their exercise did so because they pushed themselves harder. In doing so, they experienced a higher level of physiological stress as indicated by the alteration in the excretion rates of the biogenic amines and metabolites.

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PREDICTION OF THERMAL STRESS CASUALTIES

INTRODUCTION

During physical work, man increases the rate at which he converts energy and produces heat. Fortunately, the normal physiological mechanisms of temperature regulation adequately dissipate the metabolic heat unless environmental constraints exist that significantly inhibit heat loss. In a given environmental scenario, the clothing worn by the individual performing physical work is the most important factor in regulating the disposal of body heat (1).

The most important avenue of heat loss to a working human is often the evaporation of sweat from the skin. The rate of evaporation from the body surface is proportional to the vapor pressure gradient. It is also advantageous to use non-evaporative cooling (sensible heat loss) to the extent possible to maximize cooling and conserve body water. Non-evaporative cooling occurs through radiation, convection, and conduction and is proportional to the effective surface area for heat transfer. When wearing clothing and protective equipment, man operates within the confines of a microclimate that is influenced primarily by his garment ensemble and by the task (workload) being performed. External climatic conditions are also an influence, but vary as they interact with characteristics of the clothing being worn (24).

Under conditions of protective garment wear, both core and skin temperatures can be elevated because evaporative heat loss is attenuated by the vapor pressure gradient restraints, and convective heat loss is reduced in proportion to the insulation added. Moreover, warm or hot environments can seriously impair one's ability to perform extended physical work while wearing protective garments such as the chemical defense ensemble (CDE).

Although work capacity has been observed to be diminished in all subjects when performing in the heat (21), it has been suggested that it is difficult to reliably predict an individual's persistence for work in a hot environment (5). In particular, apparently there is a certain subpopulation that is predisposed to volitional exhaustion before body heat storage reaches critical levels.

The purpose of this investigation was to further investigate the relationship between core temperature (heat storage) and thermal casualties (intolerance as reflected by premature volitional cessation of exercise in the heat). The principal focus of this work was on the observed patterns of biochemical response that accompany the perturbation of the physiological system resulting from exercise under conditions of thermal stress. By standardizing the relative physical workload, we believed the psychological component of stress could be assessed. We anticipated this approach would, under field conditions, provide a better understanding of the relationship between the actual physiological thermal stress (imposed by the CDE with physical work in the heat) and work persistence.

Most investigations of the human stress response feature one or, at the most, a small number of biochemical indices. These univariate studies have most often observed the adrenergic or noradrenergic systems. The dopaminergic and serotonergic systems have been examined more frequently in recent work (7-10, 16,17), but the simultaneous examination of all these systems is uncommon. Attempts to explain stress and performance from the activities of a single system have been moderately fruitful; however, studies more comprehensive in their treatment of these neurotransmitters and their metabolites appear to hold greater promise for achieving a more complete understanding of the human stress response.

In lower animals, the study of neurotransmitters and their metabolites may involve the analysis of urine, blood, spinal fluid, or brain tissue. Studies using normal humans are typically limited to blood or urine. Blood analysis has the advantage of providing an event-specific glimpse of chemical levels in the bloodstream; however, it is a stressful invasive technique (which confounds the experiment) not readily adaptable to field settings. The analysis of urine from a timed sample suffers because event-specific peaks and troughs are averaged, and an abstract of the total collection period is all that can be obtained. It has the advantage, however, of being a noninvasive method where, because of the efficiency of the kidney as a trap and the controlled outflow, an excretion rate can be calculated. Thus, while no one imagines that brain events are precisely measured in the urine, timed excretion rates do indicate change by providing an integrated measure especially adaptable for use in field settings.

The biochemical profile for this experiment consisted of four neurotransmitters and their metabolites. The neurotransmitters included norepinephrine (NE), epinephrine (E), dopamine (DA), and serotonin (5HT). The metabolic end products of these neurotransmitters are vanillylmandelic acid (VMA) and 4-hydroxy-3 methoxyphenylglycol (MHPG) for NE and E; homovanillic acid (HVA) and 3,4-dihydroxyphenylacetic acid (DOPAC) for DA; and 5-hydroxyindoleacetic acid (5-HIAA) for 5HT. We hypothesized that the combined evaluation of a subset of these biochemical indicators of stress might better delineate the hypothesized relationships between physiological heat stress and work persistence.

METHODS

This experiment featured a repeated measures design wherein subjects were monitored under conditions in which the CDE, work, and heat were applied in different combinations. On the initial visit to the laboratory, each subject's maximal aerobic capacity was measured using the open-circuit method and a continuous incremental work test. Expired gas samples during exercise were collected using a computer-automated system. Gas samples were passed through a drying tube and analyzed for CO_2 and O_2 with a Beckman LB2 and four-digit OM11, respectively. Oxygen consumption was also determined for submaximal work as the subject progressed toward exhaustion. A regression equation which related workload to oxygen consumption was constructed for each subject and used to predict the workload that would represent 50% of the subject's maximal aerobic capacity. All other segments of the test profile that included work were performed at this relative workload.

The order of the remaining experimental conditions was counter-balanced. The experimental conditions used included (1) a basal (or control) condition during which the subject, wearing a USAF flight suit, remained in a seated position in an air-conditioned laboratory (T=21°C [69.8°F]), (2) a condition during which the subject, wearing the CDE (MOPP-IV), remained in a seated position in an air-conditioned laboratory, (3) a condition where, in an air-conditioned laboratory, the subject exercised at 50% of his maximal aerobic capacity wearing a USAF flight suit, (4) a condition where the subject exercised in an air-conditioned laboratory at 50% of maximal aerobic capacity wearing only the mask and hood of the CDE and a USAF flight suit, (5) a condition wherein the subject exercised at 50% of his maximal aerobic capacity wearing the complete CDE in an air-conditioned laboratory, (6) a condition where the subject exercised at 50% of his maximal aerobic capacity in a hot environment wearing a USAF flight suit, and (7) a condition in which the subject exercised at 50% of his maximal aerobic capacity in a hot environment while wearing the CDE. In conditions involving the CDE, all subjects wore USAF flight suits under the ensemble to simulate a true MOPP-IV profile. For conditions not featuring the CDE, subjects wore only the USAF flight suits.

All conditions that involved environmental heat were conducted outdoors in the desert summer and featured an environmental envelope with a narrow range of wet bulb globe temperatures (WBGT) averaging approximately 30°C (86°F). With the exercise perturbation, all subjects walked at a speed and grade estimated to result in a relative workload of 50% of their Vo_2 max either (a) for 40 min, (b) until their rectal temperatures (Tre) reached 39°C (102.2°F), or (c) until they volitionally discontinued the trial. Perceived exertion and perceived heat stress were monitored at 5-min intervals using the Borg scale. If a subject's temperature reached 39°C (102.2°F), the test was immediately terminated. Rectal temperatures were monitored using a digital thermometer placed 10 cm (4 in.) beyond the sphincter muscle. Environmental conditions for outside testing were monitored throughout each trial using a sling psychrometer and black globe thermometer. Average WBGT was calculated from these values.

Timed urine samples were obtained from the subjects during each treatment. Immediately prior to each treatment, subjects emptied their bladders and were encouraged to drink at least 250 ml of water, thereby sufficiently hydrating the subjects and reducing the chance of possible errors that might occur due to inadequate amounts of urine from later collections as well as reduced hematocrit consequent to prolonged exercise. At the close of each treatment period (normally 15-30 min post-experimental conditions), subjects were again asked to empty their bladders, and these specimens were collected for analysis. The exact length of time and the total volume were noted. A 100-ml aliquot of each sample was stabilized using 1 ml of 10% ethylenediamine tetracetic acid (EDTA) 4% thioglycolic acid (sodium salt) and stored at minus 90°C (194°F) until analyzed. Excretion data for all conditions were collected during the same time of the day to control for diurnal variation. To analyze all nine biochemical components, three different "clean-up" procedures were used. First, E, NE, and DA were analyzed according to the method of Riggin and Kissinger (22) involving initial cation exchange chromatography followed by alumina absorption. 3,4-Dihydroxybenzylamine (DHBA) was the internal standard. The final alumina eluant was injected into a high-performance liquid chromatograph with an electrochemical detector (HPLC-EC). This HPLC-EC was carried out with a Waters Resolve C^{18} 150 x 3.9 i.d. mm 5 µm reverse-phase column, protected with a Whatman Pellicular ODS (30-38 µm particle size guard column). Separation was achieved with a 0.1 M citrate-acetate pH 3.0 mobile phase containing sodium octyl sulfate as the ion-pairing agent and 10% methanol.

The DOPAC, MHPG, HVA, 5-HIAA, and VMA acids were determined by a modified method of Joseph, Kadam and Risby (12). Isovanillic acid was added as the internal standard. An organic extract of the sample was evaporated to dryness under N_2. The residue was reconstituted in H_2O, injected into the HPLC column 300 X 3.9 mm µBondapak 10 µm using 0.1 M phosphate buffer, 1.2% acetic acid pH 3.1 containing 9.1% methanol as the mobile phase. The analysis for 5HT was carried out using the modified procedure of Koch and Kissinger (13). N-methyl serotonin was added as the internal standard, and urine clean-up was achieved by cation exchange chromatography. The eluent was injected into the HPLC (with the Resolve column) using 0.5 M ammonium acetate buffer pH 5.1 containing 5.0% methanol as the mobile phase. The biogenic amines and their related metabolites were measured on-line using electrochemical detection at +0.85 vs. Ag/AgCl for NE, E and DA; +0.76 V for the metabolites, and +0.50 V for 5HT. The substances were quantified by comparing areas of the constituent amine and metabolite with their respective internal standard and to external standards.

Group differences were initially evaluated using multivariate analysis of variance, although this analysis was considered to be little more than perfunctory because the variates were not considered to be dependent among themselves. As Cooley and Lohnes (2) have pointed out, the multivariate analysis is only of primary interest when the variates cannot be split off singly or in combinations, but must be considered together. Previous research with the variates featured in the present investigation has suggested that meaningful subsets of variate combinations could be expected to be expressed. Thus, primary attention was given to the univariate tests (featuring a group by trial ANOVA followed by multiple comparison tests per condition to identify group differences on each dependent variable), with chi- square being applied to test the association between predicted and observed changes in the direction (increases or decreases) of excretion rates of the biogenic amines/metabolites featured in the experiment.

RESULTS

Characteristics of the subjects (N=15) on which complete data were obtained are shown in Table 1. The mean values for height, weight, relative body fat as indicated from the skin fold sum, and Vo_2 max were typical of those reported for young adult males of this age (25).

Biochemical responses to the various treatments are featured in Figures 1, 2, and 3 and are broken down according to the system of which they are a part; the adrenergic/noradrenergic, dopaminergic, and serotonergic systems. The excretion rates for the adrenergic/noradrenergic system (Fig. 1) feature values for E, NE, and VMA that show a pronounced elevation over those reported for adult normals under basal conditions; which suggests a peripheral stress response under all the experimental conditions. (The statistical tests contrast experimental conditions with the control condition, which was also elevated.) These results were anticipated because adrenergic/noradrenergic activity has been shown to increase with the intensity (11) and duration (6) of exercise and this activity is further elevated when core temperature increases (3), perhaps in relation to the role played in altering blood flow to enhance heat dissipation (23). As MHPG is an indicator of NE turnover in the brain (as opposed to peripheral locations), the excretion values suggest that NE metabolism in the brain may have been diminished during the experimental conditions featured in this study.

TABLE 1. CHARACTERISTICS OF THE SUBJECTS (n=15)

Variable (units)	Mean	Standard deviation
Age (years)	22.2	3.8
Height (cm)	179.9	10.0
Weight (kg)	72.3	8.4
B.S.A. (m^2)	1.90	0.12
Skin fold sum (mm)	65.3	20.8
Relative fat (%)	10.0	5.6
V_{O_2} max ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.7	5.9

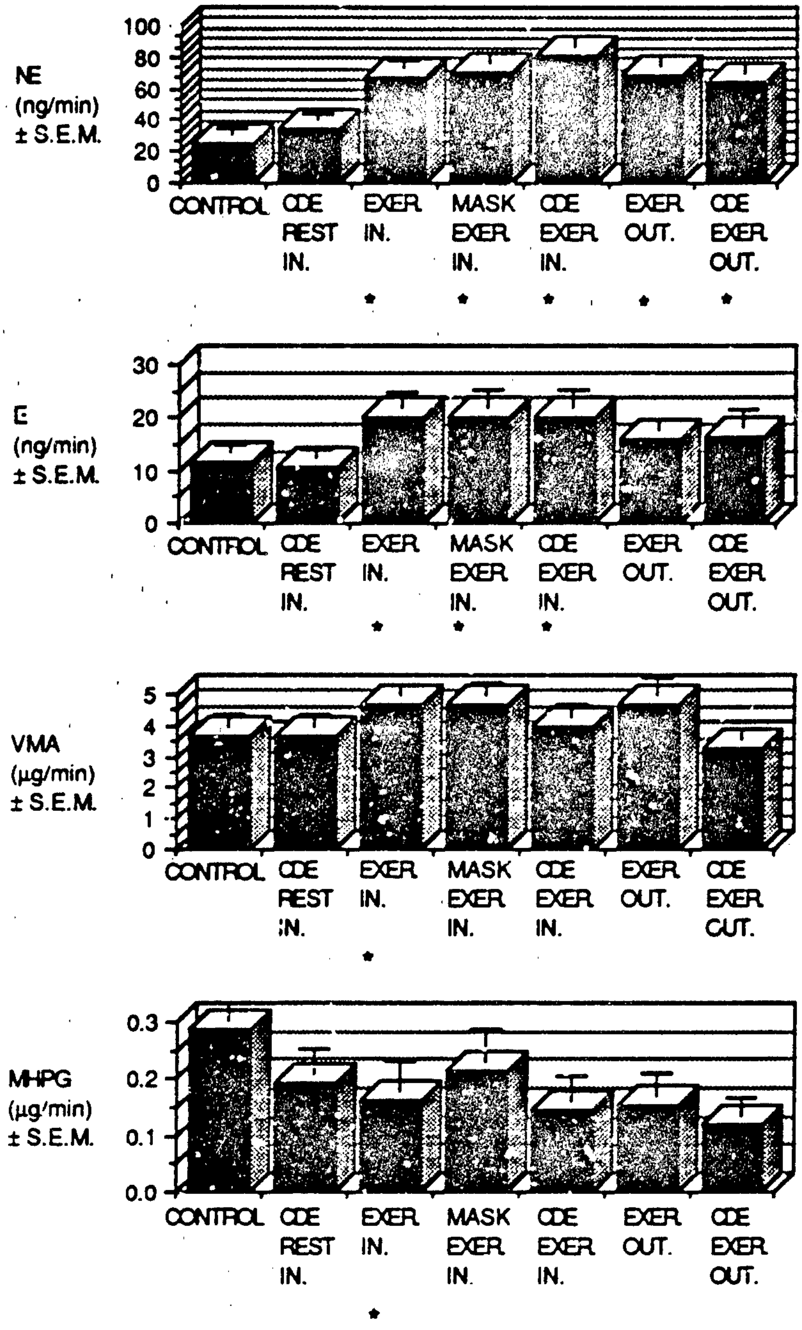

Figure 1. Response of the adrenergic system during the experimental conditions. The asterisk indicates an excretion rate which is significantly ($p \leq .05$) different from the control condition. (S.E.M. = standard error of the mean)

It is also appropriate to note the "basal seated" condition resulted in an apparent stress response in that the excretion rates all differed from normal resting values. This result is not surprising because the "basal seated" condition in an unfamiliar environment may have been both novel and perceived as constraining; both conditions could lead to an elevated response.

In the case of the dopaminergic system (Fig. 2), apparently both the secretion and metabolism of DA decreased during the experimental conditions, although the difference failed to achieve statistical significance. The patterns of the excretion responses of DA and its metabolites (DOPAC and HVA) are very congruent, suggesting that decreases in secretion were accompanied by roughly proportional decreases in metabolism. The responses of the serotonergic system to the experimental conditions are shown in Figure 3. Again, there is good coherence between the patterns of the excretion of serotonin and its metabolite, 5-HIAA. As in the case of the dopaminergic system, the response of the serotonergic system appears to have been one of reduced activity under the experimental conditions, both in the secretion of the neurotransmitter and in its metabolism.

Other data characterizing the subjects' responses to the various experimental conditions are contained in Table 2. We might note here that wearing the CDE resulted in heart rates that fall in the low resting range for young adult males. Exercise in the CDE, however, resulted in a greater heart rate when performing walking on the treadmill both indoors and outdoors. Subjects lost weight in every condition that featured exercise. Weight loss was greatest under conditions of exercise performed outdoors with the CDE. A check of the accuracy of the selection of a grade and speed for the subjects was conducted under the indoor condition where the subject performed on the treadmill wearing only a USAF flight suit. The prediction was quite accurate in that the percent of Vo_2 max achieved (52.3%) was very close to the target value of 50%.

As the hood and breathing mask of the CDE created a condition of more labored breathing in some subjects, lactic acid levels were checked under conditions of treadmill exercise wearing only the USAF flight suit and wearing the flight suit with the hood and breathing apparatus only. In each of these conditions, blood lactate levels were very close to what are normally considered to be resting levels, which suggests that the subjects were performing below a threshold for lactate accumulation and were not having difficulty with hypoxia.

Rectal temperatures at the termination of exercise tended to become progressively higher as the environmental conditions became more severe. All conditions featuring exercise resulted in Tre that were significantly ($P<0.05$) higher than the condition in which subjects sat quietly indoors while wearing the CDE. By comparing Tre of conditions III, V, VI and VII, we concluded that exercising outdoors elevated Tre approximately 0.3°C (32.54°F)

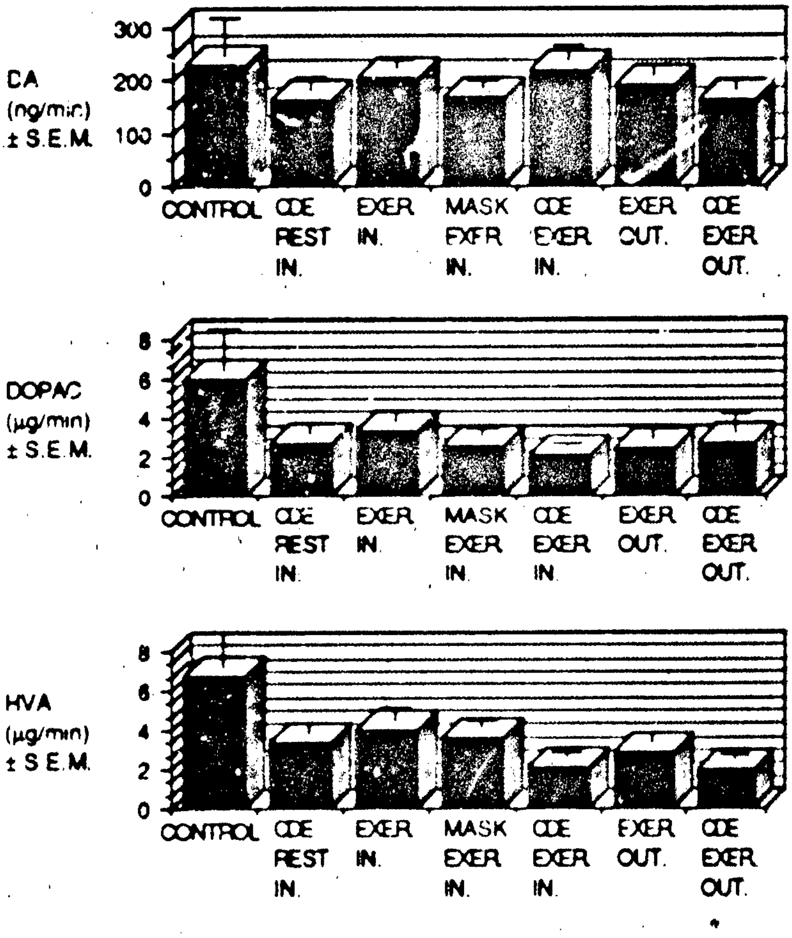

Figure 2 Response of the dopaminergic system during the experimental conditions. The asterisk indicates an excretion rate which is significantly ($p \leq .05$) different from the control condition. (S.E.M. = standard error of the mean)

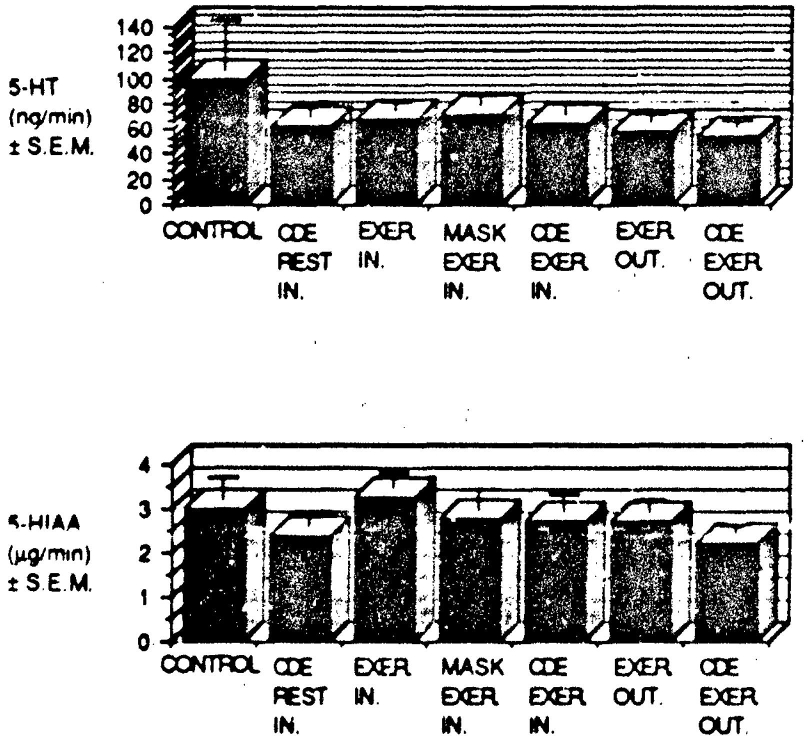

Figure 3. Response of the serotonergic system during the experimental conditions. (S.E.M. = standard error of the mean)

TABLE 2. PHYSIOLOGICAL RESPONSES AND PERCEPTION OF SUBJECTS TO THE EXPERIMENTAL CONDITIONS

CONDITIONS	II	III	IV	V	VI	VII
Exercise	-	+	+	+	+	+
Heat	-	-	-	-	+	+
CDE complete	+	-	-	+	-	+
CDE mask only	-	-	+	-	-	-
VARIABLES[a]						
Relative work (% $\dot{V}O_2$ max)		52.3				
Tre (°C [°F])	36.9 (98.42)	37.8 (100.04)	37.9 (100.22)	38.3 (100.94)	38.1 (100.58)	38.6 (101.48)
Heart rate (BPM)	66.5	138.9	141.1	165.1	155.9	194.4
Borg scale/ exertion	6.7	11.4	12.1	14.1	10.9	16.1
Borg scale/heat	8.7	12.3	13.2	15.6	12.9	18.4
Blood lactate (mM/l)		1.2	1.06			
Weight Loss: pre-post (kg)	0.12	1.15	1.25	2.01	1.87	2.17
Temp (°C [°F])	21.0 (69.8)[b]	21.0 (69.8)[b]	21.0 (69.8)[b]	21.0 (69.8)[b]	30.5 (86.9)[c]	29.1 (84.38)[c]

[a] Values at the end of each trial
[b] Dry Bulb
[c] WBGT

over values from exercising indoors, wearing the CDE while exercising elevated temperatures 0.5°C (32.44°F) (indoors or outdoors), and the combination of these two stressors (CDE plus ambient heat) elevated temperatures 0.8°C (33.44°F). The highest Tre occurred when the subjects were performing outside wearing the CDE.

An examination of the Borg scale responses in perceived exertion also reflects the cumulative effect of physical work, environmental heat, and the CDE. The highest perceived exertion occurred when all three stressors were present. The same pattern was illustrated in the perceived exertion of the heat load when the Borg scale was used to have subjects attempt to subjectively quantify differences in their perceptions of heat stress alone. In both outdoor trials the heat stress number indicated by each subject was greater than the number selected to represent exercise stress.

The primary purpose of the study was to examine differences in the biochemical response to the exercise, CDE, and environmental heat conditions as they differentially influenced subject performance. In particular, we anticipated that the pattern of biochemical response might be different in subjects unable to persist in their exercise as opposed to those who were able to push themselves further during work performance in the heat while wearing the CDE. For the purpose of examining these contrasts, subjects were divided into two groups. Subjects showing high tolerance for work under these conditions (because their final Tre exceeded 38.5°C (101.3°F) and they persisted in exercise wearing the CDE in the heat for more than 30 min) were placed in one group, hereafter referred to as the high group (n=9). The remaining subjects, all of whom showed a low tolerance for work under these conditions (because of their inability to persist for at least 30 min coupled with the failure of their Tre to reach 38.5°C) were placed in a second group, hereafter referred to as the low group (n=6). Descriptive characteristics of these subgroups are provided in the Appendix. There were no differences between these two subgroup samples on the physiological indices featured in the investigation.

Figures 4 through 18 data contrast the biochemical responses of the high and low tolerance groups on all the experimental conditions. (Corollary tabled data are presented in the Appendix.) Although there was but one statistically significant difference which occurred under the condition which featured exercise in the heat wearing the CDE (that being a significantly higher excretion rate of HVA on the part of the low group: see Fig. 9), when viewed in their entirety, the data suggest that the subjects who persisted actually pushed themselves harder and that a more pronounced stress response accompanied their effort. Although many of the mean differences lack statistical significance, this contention is supported by the trend toward higher values for E, NE, the sum of E plus NE (noted because the sum is a widely used index of stress, not because the sum

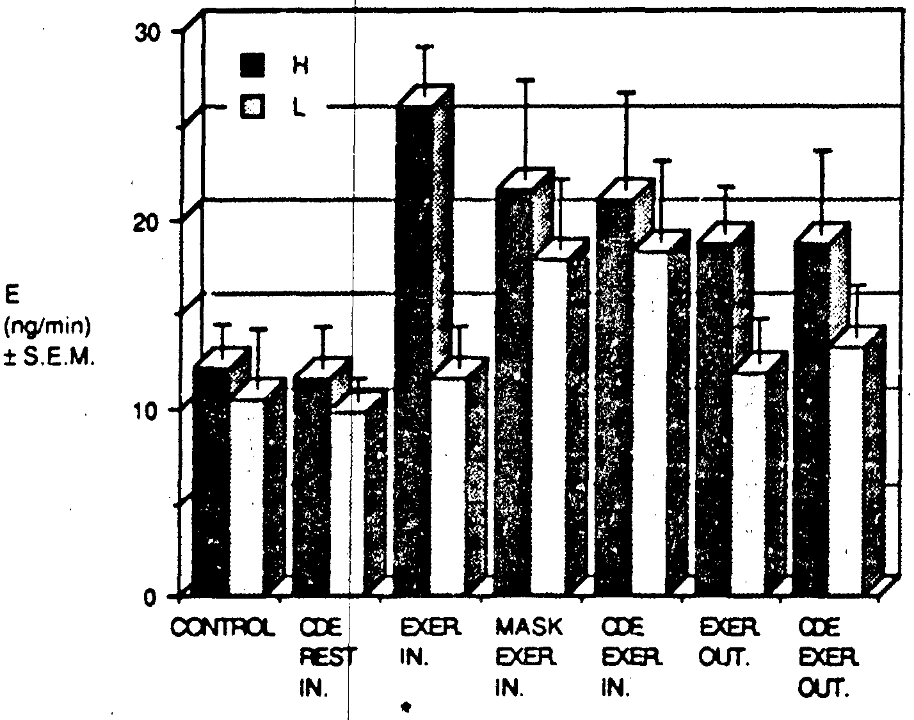

Figure 4. Epinephrine excretion rates of high and low groups under the seven experimental conditions. (* indicates $p \leq .05$)

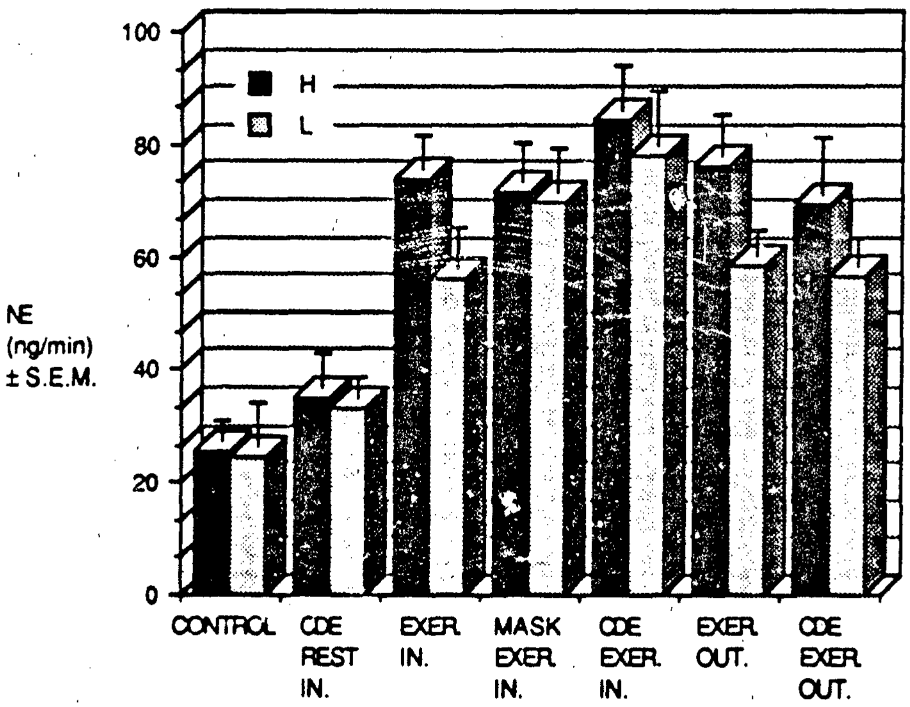

Figure 5. Norepinephrine excretion rates of high and low groups under the seven experimental conditions.

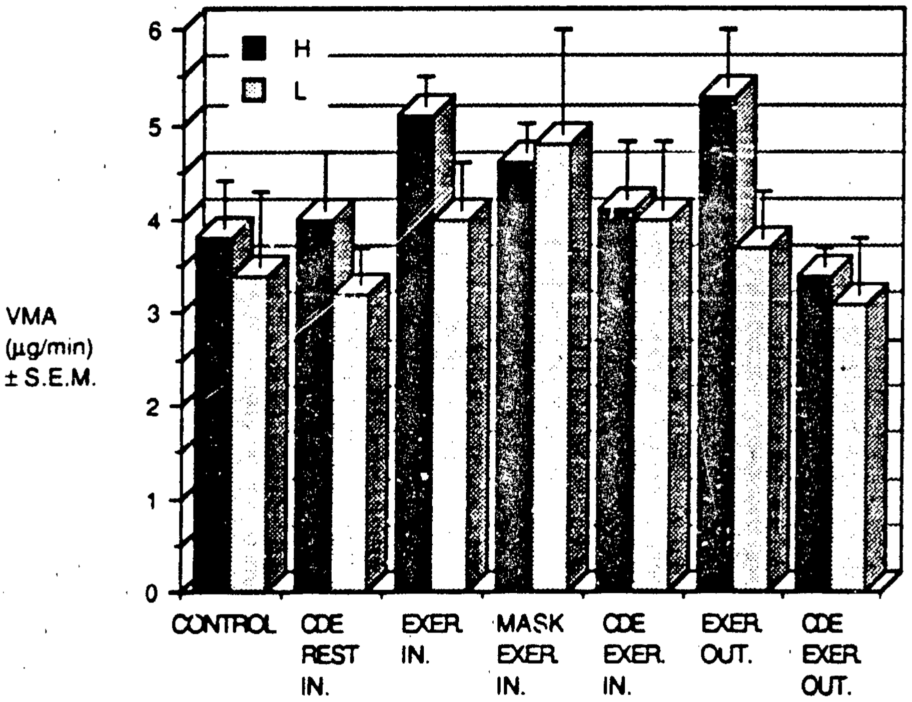

Figure 6. 3-Methoxy,4-hydroxy mandelic acid excretion rates of high and low groups under the seven experimental conditions.

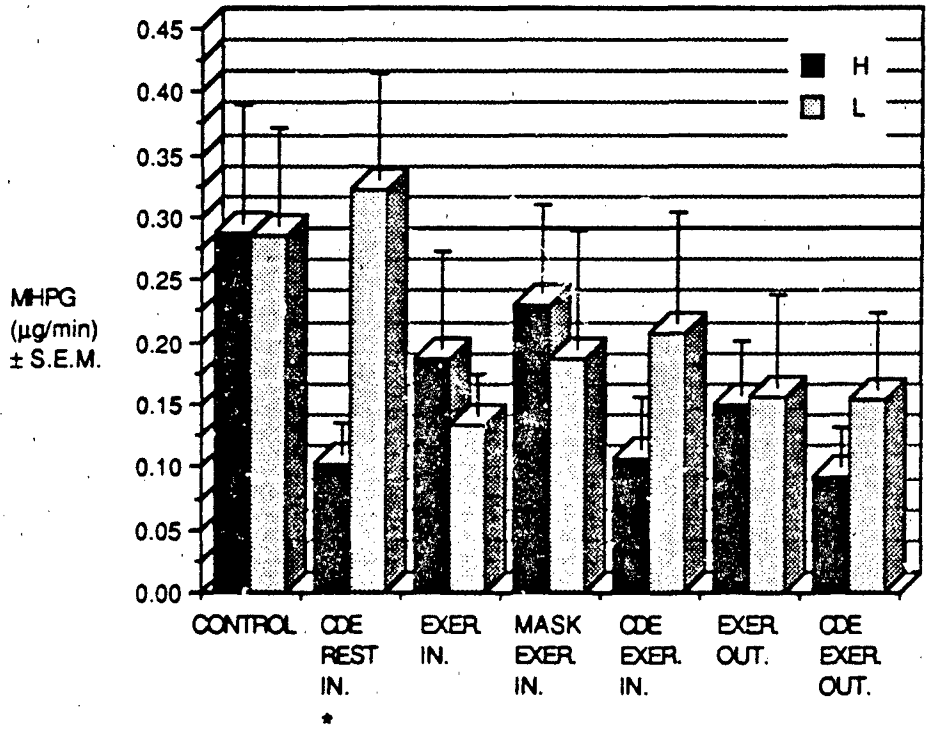

Figure 7. 3-Methoxy,4-hydroxy phenylethyleneglycol excretion rates of high and low groups under the seven experimental conditions. (* indicates p≤.05)

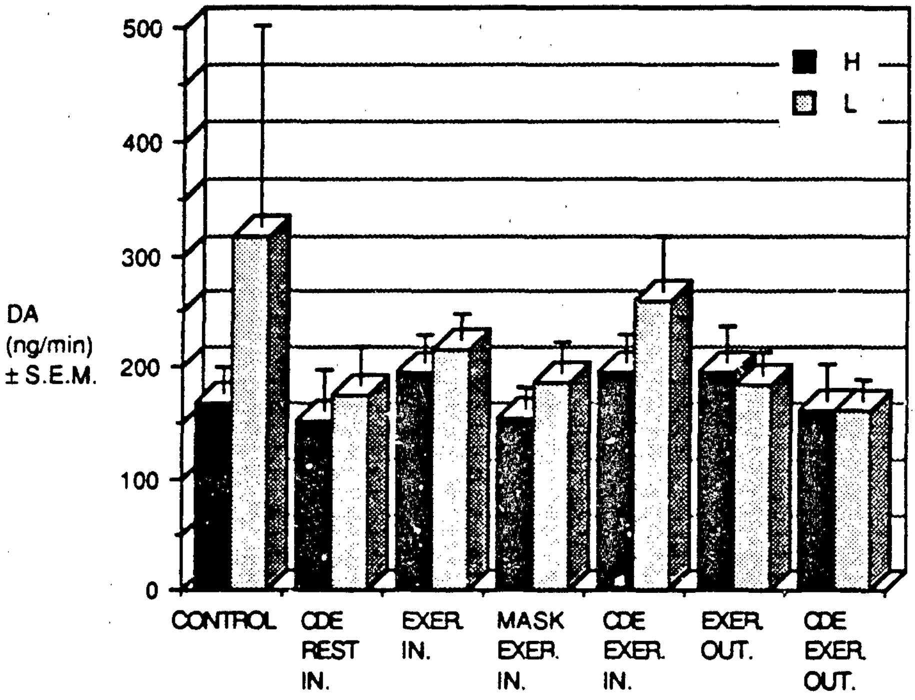

Figure 8. Dopamine excretion rates of high and low groups under the seven experimental conditions.

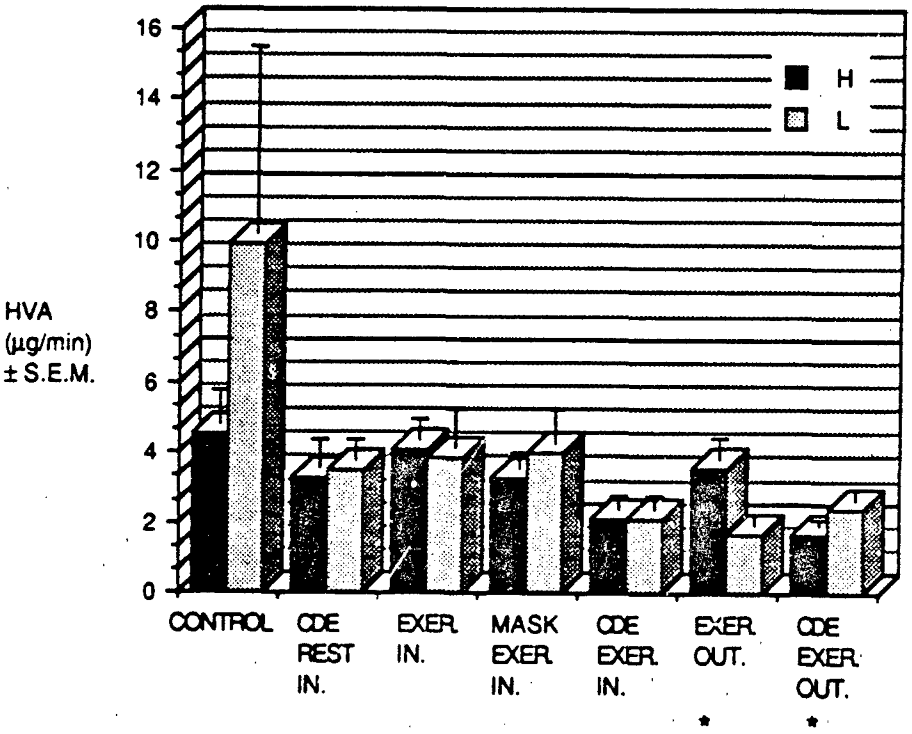

Figure 9. Homovanillic acid excretion rates of high and low groups under the seven experimental conditions. (* indicates $p \leq .05$)

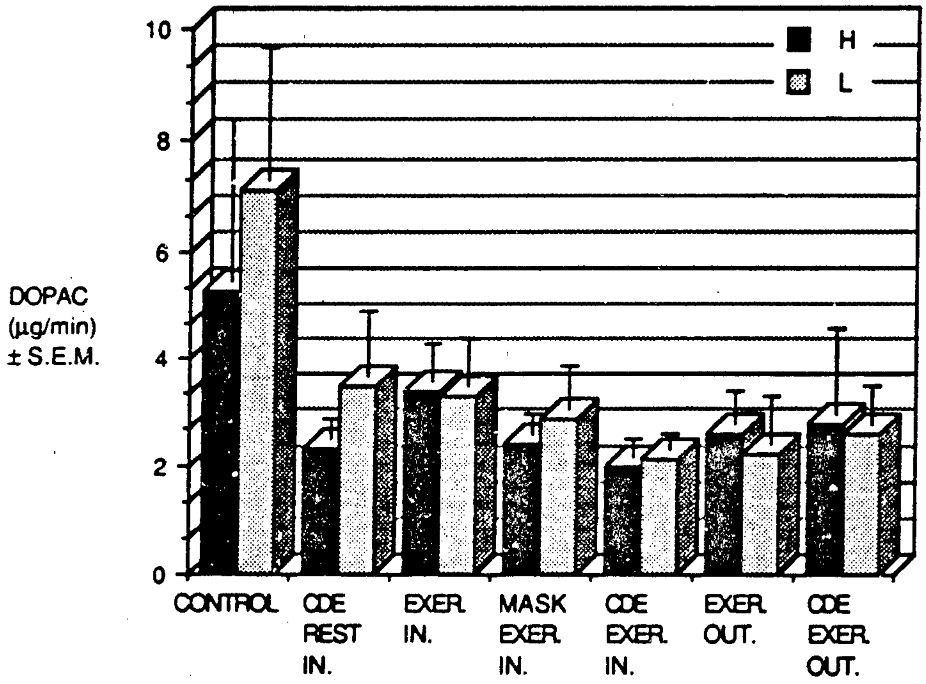

Figure 10. 3,4-Dihydroxyphenylacetic acid excretion rates of high and low groups under the seven experimental conditions.

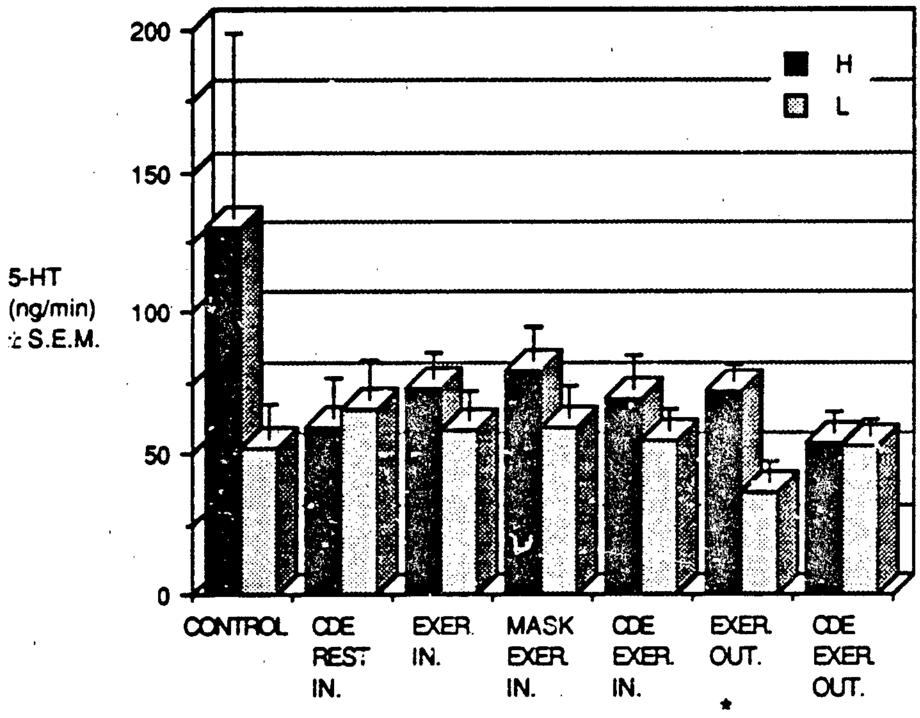

Figure 11. Serotonin excretion rates of high and low groups under the seven experimental conditions. (* indicates p≤.05)

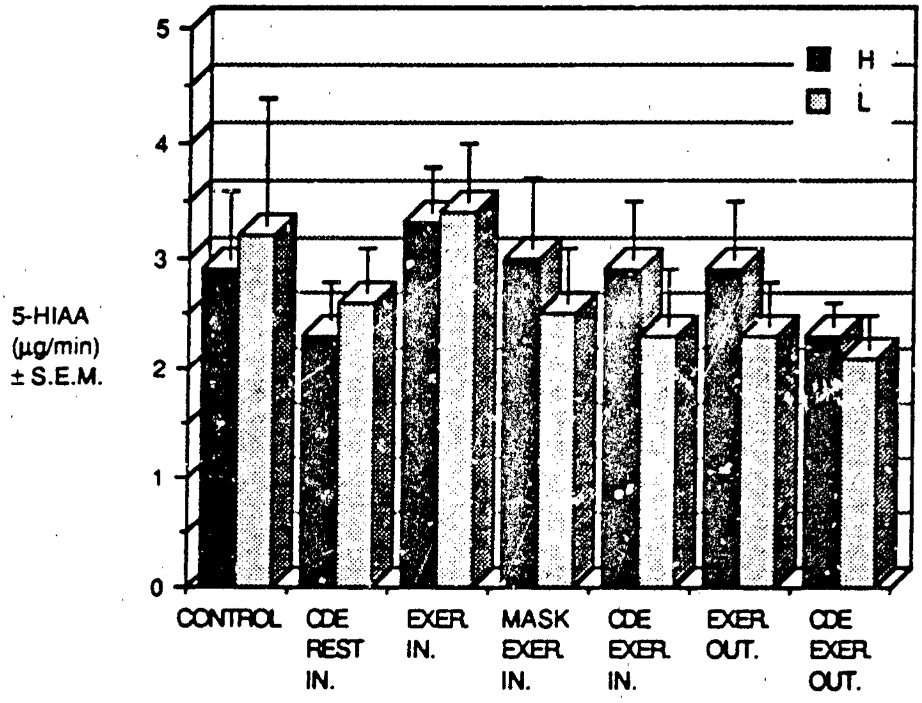

Figure 12. 5-Hydroxyindoleacetic acid excretion rates of high and low groups under the seven experimental conditions.

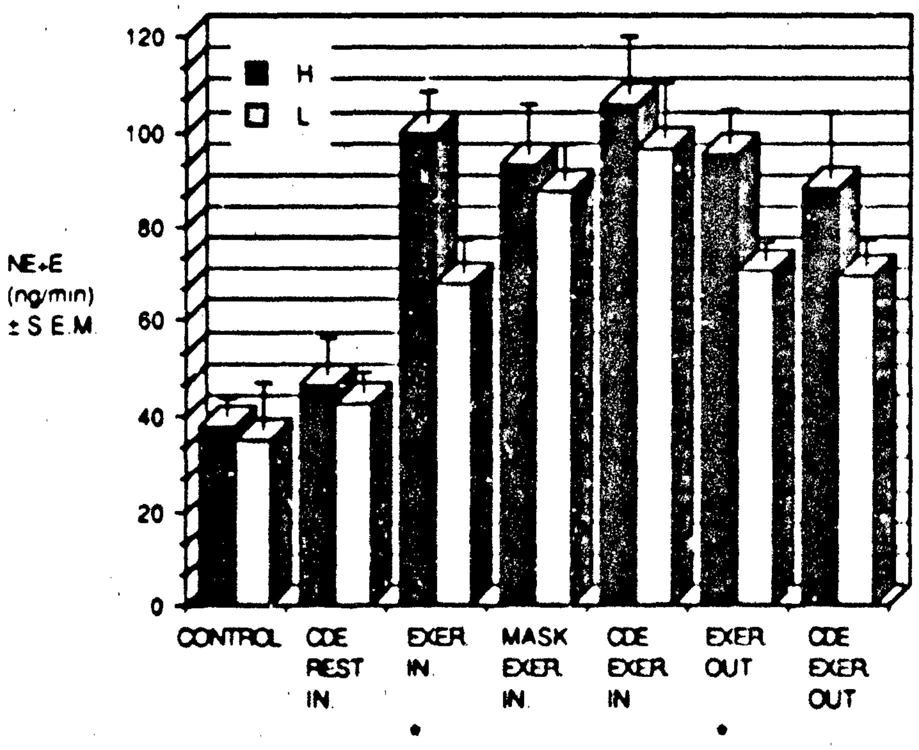

Figure 13. Sum of NE and E excretion rates of high and low groups under the seven experimental conditions. (* indicates p≤.05)

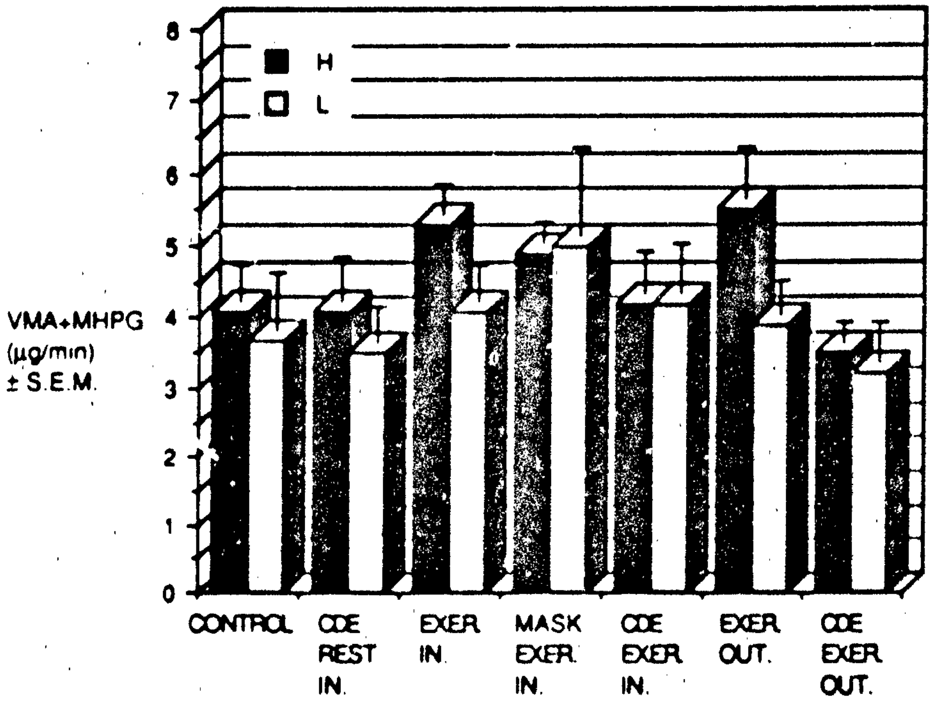

Figure 14. Sum of VMA and MHPG excretion rates of high and low groups under the seven experimental conditions.

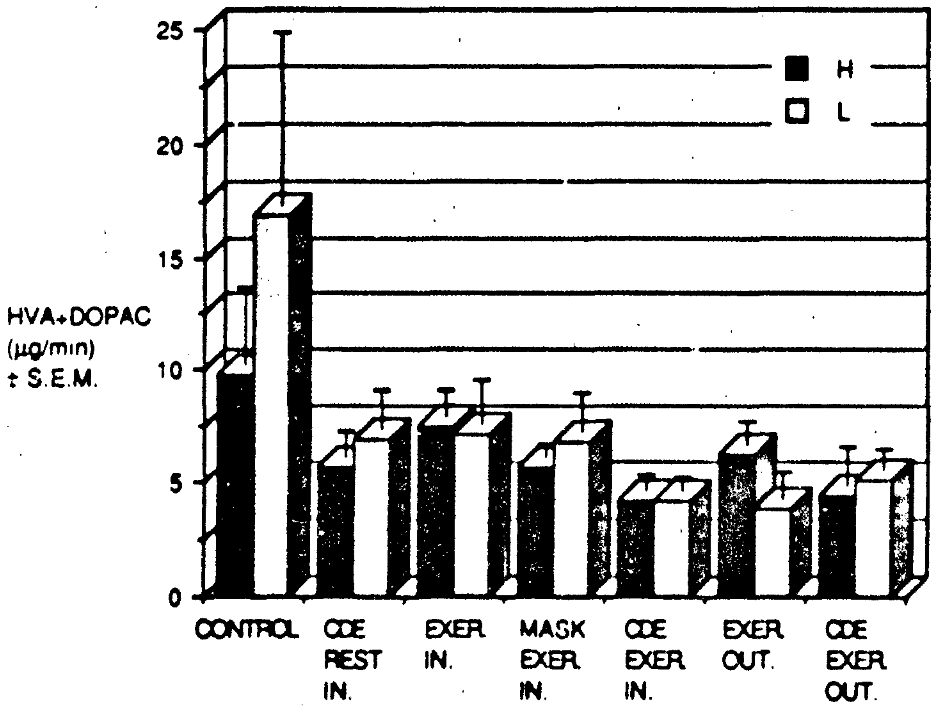

Figure 15. Sum of HVA and DOPAC excretion rates of high and low groups under the seven experimental conditions.

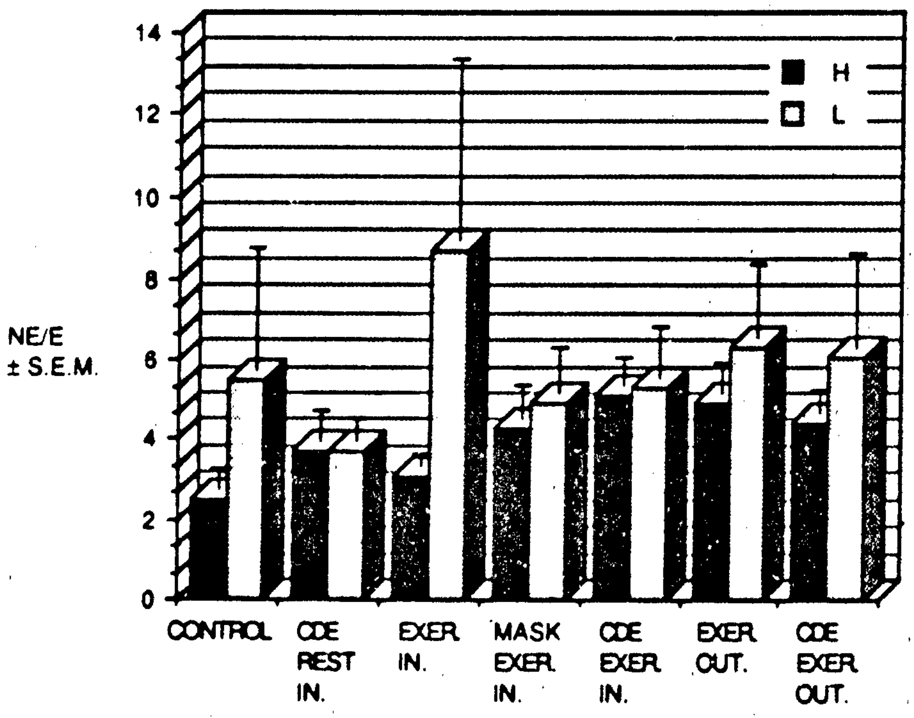

Figure 16. NE/E excretion rates ratio of high and low groups under the seven experimental conditions.

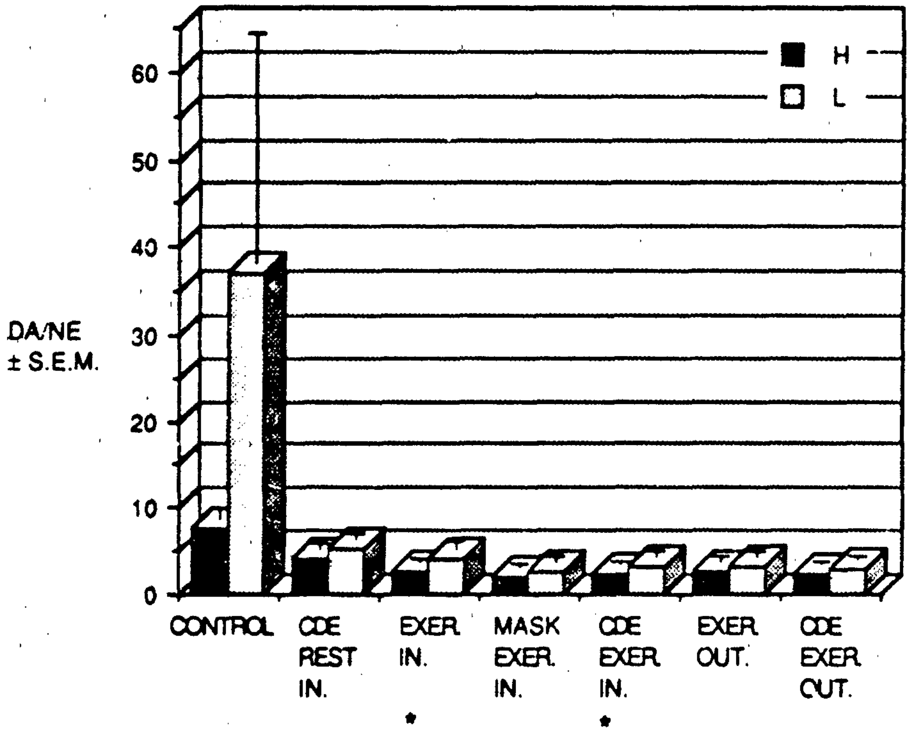

Figure 17. DA/NE excretion rates ratio of high and low groups under the seven experimental conditions. (* indicates $p \leq .05$)

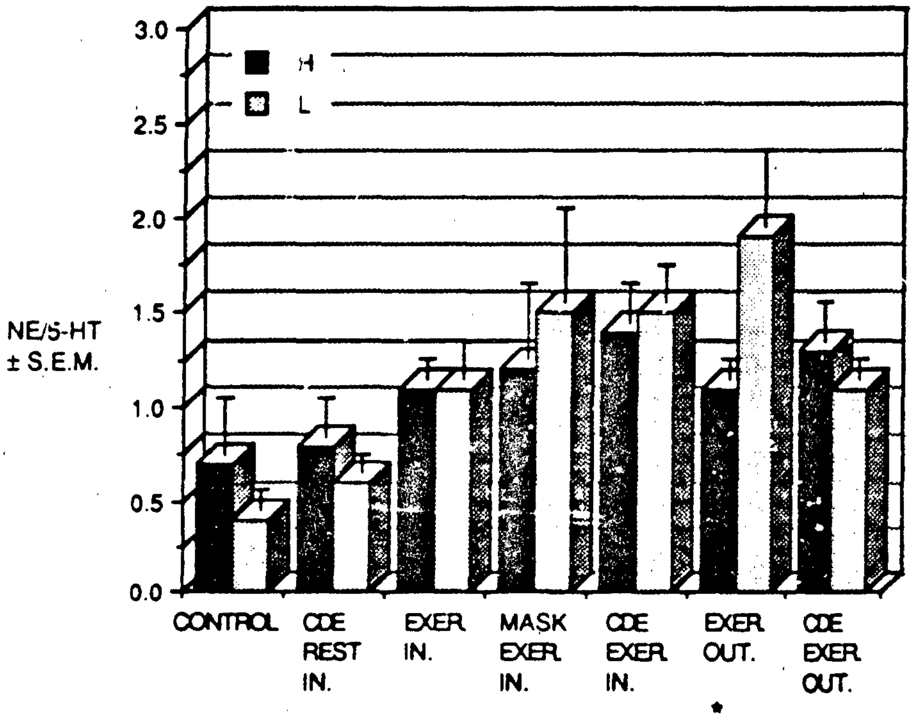

Figure 18. NE/5-HT excretion rates ratio of high and low groups under the seven experimental conditions. (* indicates p≤.05)

represents independent information), the ratio of NE to 5HT, and lower values for the ratio of NE to E and the ratio of DA to NE. In each of these instances, the direction of the difference between the mean values is in the direction which from previous experiments (given the absolute excretion rates involved) (16) suggests that a greater level of stress was experienced by the subjects who exhibited high tolerance for exercising in the heat. Although changes in these biochemical indices were not individually different statistically, the fact they all fell in a direction which agrees with earlier research suggests that the differences were reliable. Further confidence in this interpretation is provided by a chi square test (4). This test allows for a comparison between the observed agreement or disagreement with what would be expected if no pattern exists. Table 3 contains a summary of this analysis. The association is significant ($P<0.05$), which indicates that the pattern which has been observed is unlikely to have precisely matched the prediction merely by chance.

Interestingly, if one looks for performance in the experimental conditions featuring only one or two of the three potential stressors as suggestive of who will persist under the most extreme conditions (when all three stressors are present), almost identical trends are observed. In the case of exercise outdoors wearing only a USAF flight suit, many of the differences which failed to achieve statistical significance under the criterion condition do achieve statistical significance. The direction of differences on five of the six variables just noted matches what would have been predicted from earlier experiments. In a less dramatic but equally consistent way, the same trends are evidenced in the exercise condition conducted indoors wearing only a USAF flight suit. Apparently, under any condition of exercise, the group that persisted did so with an accompanying relatively greater stress response. We may argue that the greater activation of neurotransmitter systems helped them accomplish this feat.

As all subjects were performing at the same workload relative to their maximal capacity, differences in the excretion rate of the relative biochemical substances may give an indication as to the emotional state of the subject. In past studies involving extreme levels of stress, where the physical component is low to moderate, the ratio of NE to E has been useful in examining the subject's mental state (14, 15, 18, 19, 20). Most of these experiments have involved tasks that are largely perceptual motor in nature and have not involved exhausting physical work. In these earlier studies, the better performers tended to exhibit an excretion rate featuring an imbalance which favored NE; subjects performing less capably frequently showed greater balance in the proportion of NE to E. In the present investigation, there was a large variation in the subject responses, particularly in the group that failed to persist under extreme conditions of work in the heat. This variation, coupled with the small number of subjects, leads to a nonsignificant

TABLE 3. A COMPARISON DURING EXERCISE OUTDOORS IN THE CDE OF BIOGENIC AMINE/ METABOLITE VALUES BETWEEN THOSE INDICATED BY EARLIER RESEARCH AND THOSE OBSERVED IN SUBJECTS FROM THE HIGH AND LOW GROUPS

	Direction of change (from normal resting values) by a stress perturbation (16)	Direction of difference of mean values for the high versus low groups
Variable	"Prediction"	"Result"
E	higher	higher
NE	higher	higher
E+NE	higher	higher
NE/5HT	higher	higher
NE/E	lower	lower
DA/NE	lower	lower

Note: The difference between high and low groups occurred in the "predicted" direction on all six variables (chi-square=6.0; p<0.05).

result; however, the ratios suggest that the subjects that persisted (high tolerance group) actually experienced a greater emotional component relative to the physical component. This data differs from what has been observed in an earlier experiment featuring a perceptual motor task (16), but may be attributable to the fact that the current task was much more physical in nature, and that NE played a significant role in facilitating the circulatory adjustments that would be necessary to accommodate the heat stress (23).

During the analysis of the catecholamine metabolites, examination of the HPLC-EC chromatograms revealed several unknown constituents systematically detected along with the metabolites. The data from the unknown constituents along with the known metabolites were used to search for differences in the HPLC-EC elution patterns between the high and low performance groups. Results using Ward's Minimum Variance Cluster Analysis on the known and unknown constituents indicated two separate elution patterns from the condition of exercise, indoors with the CDE mask alone. These data suggest the unknown constituents may help elucidate the effects of the CDE on performance and should be investigated further.

As physiological and biochemical data were being collected to look at different possible group differences that would help predict performance under extreme levels of heat stress by wearing the CDE, it was also deemed advisable to look at several basic aspects of personality, including an index of personality traits and a profile of mood states. The results of this analysis are contained in Table 4. There were no significant differences on the Profile of Mood States Inventory although statistical significance was nearly achieved ($p = 0.12$) for the T scale, with the HIGH group (persisters) showing a slightly lower mean value. The Eysenck inventory (Table 4) of personality traits also failed to differentiate between the two groups, although statistical significance was nearly achieved on the "extroversion" scale, with the HIGH group (persisters) showing a slightly lower score.

CONCLUSIONS

The data support the conclusion that subjects who persisted in their exercise under conditions of heat while wearing the CDE did so because they were able to push themselves harder than their counterparts who failed to persist. This effort was accompanied by a greater biochemical response, the pattern of which (given the absolute excretion rates) suggests a higher level of physiological stress. The behavior of the various neurotransmitters as indicated by excretion rates of their free state (unconjugated) and of their metabolites in the urine form a coherent profile suggesting a greater stress response both from a physical and a psychological perspective. The subjects who

TABLE 4. PSYCHOLOGICAL STATES AND TRAITS OF THE EXPERIMENTAL GROUPS

Inventory	Item	Group	$\bar{x}$	SD	Signif.
Profile of Mood States	T-scale	High	7.4	2.7	.12
		Low	9.7	2.3	
	D-scale	High	3.6	4.2	.21
		Low	6.0	2.0	
	A-scale	High	4.4	4.3	.52
		Low	6.0	4.7	
	V-scale	High	20.2	4.9	.79
		Low	20.8	3.7	
	F-scale	High	6.6	2.7	.88
		Low	6.8	4.8	
	C-scale	High	1.6	2.1	.72
		Low	4.5	4.9	
Eysenck	E-scale	High	11.1	3.4	.07
		Low	14.7	3.5	
	N-scale	High	8.4	3.9	.90
		Low	8.7	2.9	

persisted in the exercise did so because they had the "mental toughness" to tolerate a greater effort and the accompanying discomfort.

Although no simple marker or predictor of persistence presented itself, there were several provocative findings. First, significant differences in the excretion profiles of high and low persisters were observed under conditions of exercise without the CDE in an air-conditioned laboratory. Second, a heuristic aspect of the study revealed that a cluster analysis featuring known and unknown constituents clearly identified and separated six of the subjects who were able to persist. Further study along these lines appears to hold promise for enhancing the ability to predict thermal stress casualties.

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APPENDIX

COROLLARY DATA

TABLE A-1. CHARACTERISTICS OF THE LOW AND HIGH WORK TOLERANCE EXPERIMENTAL GROUPS

Variable (Units)		LOW (n=6)	HIGH (n=9)	SIGNIFICANCE (t-test)
Age (years)	M	20.8	23.2	0.28
	SD	2.6	4.6	
Height (cm)	M	176.7	182.0	0.12
	SD	6.6	5.6	
Weight (kg)	M	72.3	72.3	1.00
	SD	7.6	8.8	
B.S.A. (m^2)	M	1.89	1.93	0.54
	SD	0.09	0.14	
Skin fold sum (mm)	M	72.3	60.8	0.31
	SD	24.6	18.2	
Relative fat (%)	M	10.7	9.5	0.31
	SD	6.0	5.4	
V_{O_2} max (ml· kg^{-1}·min^{-1})	M	48.5	48.8	0.93
	SD	5.4	6.4	

Note: None of the group mean differences is significant (P=0.05).

TABLE A-2. BIOGENIC AMINE/METABOLITE EXCRETION EXPERIMENTAL GROUP MEANS AND STANDARD DEVIATIONS

Conditions		I		II		III		IV		V		VI		VII	
Exercise		-		-		+		+		+		+		+	
Heat		-		-		-		-		-		+		+	
CDE Complete		-		-		-		-		+		-		+	
CDE Mark Only		-		-		-		+		-		-		-	
Amine, Metabolite, Sum or Ratio	Group	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
E	HIGH	12.2	5.3	11.6	6.8	26.0	7.9	21.6	15.6	21.1	15.3	18.7	7.6	18.8	13.2
	LOW	10.5	7.9	9.9	3.2	11.6	5.3	11.6	9.0	18.3	10.5	11.9	5.7	13.3	6.7
NE	HIGH	25.6	10.6	35.0	18.7	73.8	17.5	71.6	21.4	84.7	22.5	76.4	21.5	69.4	29.6
	LOW	24.8	19.0	33.2	9.6	56.0	18.4	69.9	18.5	78.1	23.9	58.6	11.3	56.5	12.8
VMA	HIGH	3.83	1.54	4.02	1.84	5.13	0.98	4.63	0.86	4.06	1.65	5.31	1.90	3.40	0.73
	LOW	3.41	2.00	3.22	1.02	4.02	1.17	4.79	2.67	3.98	1.74	3.75	1.21	3.05	1.48
MHPG	HIGH	0.29	0.28	0.10	0.08	0.19	0.24	0.23	0.22	0.11	0.12	0.15	0.15	0.09	0.09
	LOW	0.28	0.19	0.32	0.21	0.13	0.08	0.19	0.23	0.21	0.22	0.16	0.18	0.16	0.15
DA	HIGH	168.9	69.4	152.8	107.1	195.8	74.4	156.3	54.7	196.2	73.4	197.2	91.1	162.7	96.4
	LOW	317.4	430.6	176.3	84.0	218.1	52.0	188.3	63.1	259.4	118.0	185.2	50.9	161.9	44.4
HVA	HIGH	4.42	3.08	3.35	2.49	4.10	1.92	3.31	1.13	2.13	1.11	3.62	1.90	1.68	0.44
	LOW	9.86	13.00	3.49	1.50	3.93	2.80	3.98	2.43	2.10	0.89	1.71	0.80	2.42	0.83
DOPAC	HIGH	5.29	8.83	2.33	1.29	3.44	2.10	2.39	1.20	2.04	0.99	2.64	1.78	2.82	4.85
	LOW	7.07	5.81	3.48	2.96	3.31	2.31	2.94	1.87	2.07	0.76	2.21	2.20	2.63	1.60
5HT	HIGH	130.8	193.1	59.3	42.3	73.0	26.3	79.4	35.1	69.5	35.9	72.3	17.1	54.1	21.5
	LOW	51.8	30.1	65.8	32.8	58.7	23.6	59.2	26.5	54.6	17.4	36.9	17.1	53.4	13.4
5HIAA	HIGH	2.94	1.74	2.33	1.25	3.26	1.28	3.04	1.93	2.90	1.52	2.91	1.42	2.34	0.65
	LOW	3.16	2.60	2.57	1.07	3.38	1.56	2.49	1.20	2.30	1.29	2.31	1.08	2.10	0.65
E+NE	HIGH	37.8	12.2	46.6	24.0	99.8	19.9	93.2	31.0	105.8	35.4	95.1	21.6	88.2	40.6
	LOW	35.3	24.1	43.1	9.7	67.7	18.1	87.9	18.4	96.4	27.9	70.5	9.7	60.8	12.3
VMA + MHPG	HIGH	4.12	1.59	4.12	1.89	5.31	1.07	4.86	0.94	4.16	1.75	5.46	1.98	3.49	0.76
	LOW	3.70	2.03	3.55	1.12	4.15	1.14	4.97	2.85	4.18	1.71	3.90	1.24	3.21	1.38
HVA + DOPAC	HIGH	9.81	10.28	5.68	3.54	7.54	3.75	5.70	1.65	4.17	2.06	6.26	2.95	4.50	5.18
	LOW	16.93	18.29	6.97	4.19	7.23	4.68	6.92	4.10	4.16	1.47	3.92	2.57	5.50	2.15
NE/E	HIGH	2.46	1.54	3.69	2.28	3.08	1.01	4.27	2.32	5.06	2.12	4.87	2.49	4.37	1.95
	LOW	5.47	7.37	3.66	1.38	8.64	10.7	4.85	2.94	5.27	3.25	6.30	4.53	6.05	5.53
DA/NE	HIGH	7.70	3.72	4.25	1.52	2.72	1.11	4.23	0.64	2.34	0.77	2.73	1.55	2.40	1.09
	LOW	16.58	44.31	5.26	1.43	4.28	1.67	2.76	1.03	3.38	1.06	3.32	1.30	2.88	0.62
NE/5HT	HIGH	0.65	1.01	0.78	0.53	1.12	0.41	1.24	1.11	1.41	0.58	1.08	0.32	1.35	0.52
	LOW	0.43	0.21	0.62	0.30	1.12	0.61	1.55	1.19	1.51	0.61	1.92	1.05	1.09	0.28

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